4.1 Overview of Costs

This chapter presents information on the economic costs of identified restoration actions that were:

- Available from previous restoration activities after actual oil discharges. Based on the research conducted, it was found that available cost information from actual restoration activities in response to oil discharges was rather limited.

- Developed from additional sources on costs of potential restoration actions from non-oil situations. Because information on actual costs of restoration activities after actual oil discharges was limited, it was necessary to develop information on costs using data from non-oil situations.

The material presented in this section follows the outline for the material presented in Chapters 2 and 3. Potential restoration actions were identified previously (See Exhibit 2.2).

Potential restoration actions cover a diverse group of activities. As discussed in Chapters 2 and 3, actions include such activities as:

- Natural Recovery;

- Replanting in a number of different environments;

- Supplementary methods to remove residual oil contamination or mitigate further injury, such as cropping vegetation, constructing erosion control structures in saltmarshes, or opening of channels in mangrove swamps;

- Bioremediation to reduce the residual oil contamination;

- Activities specific to certain structured habitats such as reconstruction or reseeding of oyster reefs or coral transplants; and

- Activities for removing residual contamination from shorelines, such as flushing, sediment washing, sediment agitation, or incineration.

Wherever possible, cost information was extracted from a detailed review of the literature. However, certain costs were not available directly from published sources. In these instances, a considerable effort was devoted to developing cost estimates based on personal communication with knowledgeable experts. In some instances a significant degree of analysis was required in order to synthesize meaningful cost information. Cost information taken from historical sources was converted to mid-1992 dollars using relative price indices. (June 30, 1992 Producer Price Index.)

4.2 Economic Costs of Restoration Actions

4.2.1 Estuarine and Marine Wetlands

4.2.1.1 Saltmarsh

Saltmarsh restoration actions include:

- Natural Recovery;
- Replanting;
- Supplementary Erosion Control Structures;
- Sediment Removal/Replacement;
- Vegetation Cropping;
- New Saltmarsh Creation;
- Low Pressure Flushing; and
- Bioremediation.

Some actions will typically be performed in addition other Salltmarsh creation is included as an off-site replacement action. It is often coupled with replanting.

4.2.1.1.1 Oil Related Literature

Actual costing information reported in the literature for specific restoration actions after an actual oil discharge were identified in two cases. The first was reported in Krebs and Tanner (1981). This involved a discharge of No. 6 fuel oil in a smooth cordgrass (*Spartina alterniflora*) saltmarsh near the mouth of the Potomac River where it enters Chesapeake Bay. The restoration action consisted of sediment removal, disposal of the sediment, and backfilling with new material coupled with replanting of smooth cordgrass (*Spartina alterniflora*). It should be noted that many observers recommend against sediment removal except in extreme situations (Getter et al., 1984; Chapter 3).

The other case involved the *Amoco Cadiz* discharge in France as reported in Seneca and Broome (1982), Getter et al. (1984), and Broome et al. (1988). The restoration action consisted of replanting of several species of local saltmarsh vegetation. Actual costs were not reported, but level-of-effort data were reported on the labor requirements for digging, separating, and transplanting.

4.2.1.1.2 Non-oil Related Literature

A number of literature sources include cost data that may be applicable to restoration efforts following an oil discharge. Much of this cost data is derived from wetland restoration work involving highway and other construction project mitigation efforts as well as work involving wetland creation on dredge spoil sites by the U.S. Army Corps of Engineers (USACOE). Key cost information on replanting and erosion control structures was extracted from USACOE (1978), Garbisch (1978), Broome et al. (1988), and Jerome (1979). Historical cost data on saltmarsh wetland creation projects was summarized from publications including Josselyn (1982), USACOE (1978), Josselyn et al. (1991), and Purcell and Johnson (1991).

4.2.1.1.3 Costs of Restoration Actions

Costs of saltmarsh restoration actions are discussed in the following subsections.

4.2.1.1.3.1 Natural Recovery

Costs of monitoring programs are discussed in Section 4.4.

4.2.1.1.3.2 Replanting

It is noted in U.S. Army Corps of Engineers (1978) that marsh replanting costs can be expected to be extremely site-specific and will reflect such factors as:

- Logistics;
- Labor-hour costs and efficiency;
- Planting design (including the density of transplants); and
- Texture of the substrate.

Exhibit 4.1 presents labor requirements for planting in saltmarsh habitats. A key factor in the labor requirements is the planting density. The level of effort involved tends to be proportional to the number of plants. Planting labor requirements are given for spacings of 0.5, 0.6, and 1.0 meters. These correspond to 40,000, 28,000, and 10,000 plants per hectare, respectively. USACOE (1978) suggests that spacings of 1.0 to 1.5 meters will result in cover in one to two years in most situations. Closer spacing will be desired if faster plant cover is required, or if erosion presents potential problems. Level-of-effort data were typically reported for one of the spacings presented. These reported data were adjusted to the other spacings by extrapolating based on the number of plants.

There are many other projects reported in the literature for which brief cost summary information is provided. Most of these typically have much lower costs. It appears that most of these cases involve much less comprehensive restoration efforts and typically are associated with wetland mitigation projects.

The two main methods of revegetation include seeding and transplanting of sprigs, plugs, or potted plants. Seed or transplant propagules may be purchased from a commercial nursery or obtained locally from a donor location.

Individual task elements for marsh re-vegetation efforts include:

- Acquiring transplant propagules (either through purchase or digging and separating) if transplanting is the chosen action;

- Actual planting of the propagules;

- Purchasing or gathering of seed, if that is the chosen action;

- Seeding;

- Fertilizing (usually); and

- Follow-up effort including monitoring and selective replanting.

As seen in Exhibit 4.1, seeding is much more economical although, as noted in Chapter 3 is less effective. In general, reported labor requirements for the manual planting of sprigs, plugs, or potted plants range from 50 to 250 hours (for 1.0 meter spacing of plants). These figures quadruple as spacing is reduced to 0.5 meters. Manual digging and separating of plants reportedly requires from 50 to 133 hours. Mechanized digging (using an adaptation of a small agricultural tractor), separating, and planting requires half the time (Broome et al., 1988)

The low figures are from Broome et al. (1988) and represent the experience of skilled wetland researchers. Allowances for normal contingencies involved in work of this type are not included. Getter et al. (1984) suggest that these times should be doubled. The high figures reported in Seneca and Broome (1982) represent plantings of local species in France and may not represent conditions in the United States. Broome et al. (1988) suggest that the reported figures based on the work of Garbisch (150 hours for planting based on 0.6 meter spacing) may be most representative since they are based on the experience of a commercial firm with extensive experience in wetland restoration projects.

The data from U.S. Army Corps of Engineers (1978) suggest that for most common saltmarsh species, planting and digging requires somewhat over 300 hours for 0.6 meter spacing. However, certain species such as big cordgrass may require somewhat more time. Since planting and digging have about equal time requirements, the U.S. Army Corps of Engineers (1978) data are consistent with the figures reported in Broome et al. (1988).

Exhibit 4.1 Reported labor requirements for saltmarsh planting.

Source	Planting Activity	Person-Hours per Hectare		
		(0.5 meter spacing)	(0.6 meter spacing)	(1.0 meter spacing)
Seneca and Broome, 1982	• Digging and separating Halimione springs	220	152	55
	• Digging and separating Puccinellia plus • Planting halimione or Puccinellia	530 1,000	368 694	133 250
Broome et al., 1988	• Manual digging and separating of S alterniflora	200	139	50
	• Mechanized digging and separating of S. alterrniflora	100	69	25
	• Manual planting of S. alterniflora	200	139	50
	• Mechanized planting of S. alterniflora	100	69	25
	• Seeding			
	♦ Harvesting seed	5 (seed spacing not applicable)		
	♦ Threshing seed	2.5 (seed spacing not applicable)		
	♦ Preparing seedbed and sowing	7.5 (seed spacing not applicable)		
	• Planting springs or potted plants using mechanical auger based on work of Garbisch	221	150	54
	• Fertilizing based on work of Garbish	65	45	16
	• Broadcasting seed based on work of Garbisch	10 (seed spacing not applicable)		
USACOE, 1978 taken from Woodhouse et al., 1972	Collecting and transplanting smooth cordgrass by hand	536	372	134
USACOE, 1978 taken from Dodd and Webb, 1975	• Digging, separating and transplanting			
	♦ Saltmarsh	452	314	113
	♦ Black needlerrush	468	325	117
	♦ Smooth cordgrass	536	372	134
	♦ Big cordgrass	844	586	211
USACOE, 1978	• Rule of thumb for:			
	♦ Transplants and sprigs		100-200	
	♦ Rhizomes, tubers and rootstocks		100-150	
	♦ Seeding		10-40	

To summarize the reported data in the literature, it appears that typical labor requirements for planting of sprigs, plugs, or potted plants (in a large field restoration project) requires about 150 hours per hectare for 0.6 meter spacing. An additional equal amount of time is required for digging, separating, and preparing plants dug from a nearby site if this operation is performed in lieu of purchasing the material from a commercial nursery. Seeding and fertilizing requires about 10 to 40 hours per hectare. If seed is harvested and threshed from a nearby site, an additional 10 to 15 hours may be required.

Exhibit 4.2 summarizes the reported cost figures in the literature for saltmarsh restoration. In this table, the reported figures are adjusted to 1992 dollars using the GNP price deflator. Garbisch (1978) reports the fully-loaded cost for seeding and fertilizing (adjusted to 1992 dollars) as $9,680 per hectare. The full-loaded cost (including travel, overhead, and profit) for mechanical planting (based on 0.6 meter plant spacing) is $29,050 per hectare. Semi-mechanical planting (using a hand auger) was $43,570 per hectare.

Broome et al. (1988) reports more detailed information (based on the work of Garbisch). In this case the fully-loaded cost (in 1992 dollars) is $40,970 per hectare. The figures of Garbisch for planting are based on greenhouse-grown plants. Material costs are a large component of costs and include $18,560 per hectare for potted seedlings. These reportedly cost $0.66 per plant. The material cost of slow release fertilizer applied at the time of planting is $2,410 per hectare. A later application of conventional broadcast fertilizer has a material cost of $482 per hectare.

The direct cost of materials and direct labor is reported at $22,650 per hectare, most of which is for materials. Adding in an allowance for travel to the restoration site, per diem, overhead and profit, and an allowance for a replanting guarantee, raises the cost to $40,970 per hectare. The replanting guarantee assumes that 20 percent of the area will be replanted over the development period.

Jerome (1979) reports lower costs. Adjusting to 1992 dollars, seeding costs are reported to range from $1,320 to $2,240 per hectare. Costs for collecting, transplanting, fertilizing, and maintaining a restored marsh are reported to range from $8,900 to $23,600 per hectare. These figures are lower than those based on the work of Garbisch. Few details are provided on the specifics of the restoration effort referred to by Jerome, but it may not include as extensive an effort as assumed by the Garbisch figures.

Exhibit 4.2 Reported costs for saltmarsh planting.

Source	Cost Item	Dollars Per Hectare (Adjusted to 1992)
Garbisch, 1978	• Loading cost for seeding and fertilizing • Loaded cost for mechanical planting (0.6 meter spacing) • Loaded cost for semi-mechanical planting (0.6 meter spacing)	$9,680 $29,050 $43,570
Broome et al., 1988 (based on information from Garbisch)	• Material costs ♦ Potted seedlings ($0.66/plant at 0.6 meter spacing) ♦ Slow release fertilizer ♦ Conventional broadcast fertilizer Labor and material costs Fully loaded costs including travel, per diem, overhead profit plus 20% for replanting guarantee	 $18,560 $2,410 $482 $22,650 $40,970
Jerome, 1979	Seeding Total costs of restored marsh Collectingjj Transplanting Fertilizing Maintaining	$1,340 - $2,240 $8,900 - $23,600
USACOE, 1978	Commercially grown transplants (0. meter spacing)	$7,700 - $41,000

King (1990) notes the problem that many costs associated with restoration in mitigation projects are much lower than could reasonably be expected if the project were to be "true" (i.e., fully successful) restoration. This is because there is frequently considerable pressure to perform the job at the lowest possible cost, so the results are frequently poor.

U.S. Army Corps of Engineers (1978) reports a range of costs for commercially-grown transplant stock. Based on 0.6 meter spacing the cost of transplants ranges from $7,700 to $41,000.

Synthesizing from the data reported in the literature, it appears that figures in the range of $10,000 per hectare are reasonable for a quality seeding effort. Costs in the range of $30,000 to $45,000 per hectare are reasonable using greenhouse-grown transplant stock. Costs on any individual project are highly variable. Some of these key cost variables include:

- The method of marsh establishment (seeding or transplanting);
- The plant spacing in the case of transplanting; and
- Whether or not greenhouse-grown nursery stock is used.

4.2.1.1.3.3 Supplementary Erosion Control Structures

Woodhouse (1979) presents some costs for temporary protection from erosion. Slat-type sand fence costs $3.90 to $5.40 (in 1992 dollars) per linear meter of protection for materials including posts and braces. Installation labor was estimated to be 0.1 person hours per meter in addition to the material costs. Woodhouse (1979) also states that the least expensive sandbag devices cost less than $20 per linear meter.

U.S. Army Corps of Engineers (1978) presents the costs of erosion control structures originally developed for wetland creation on dredged material in exposed locations. The cost of heavy sandbag dikes per linear meter (1992 dollars) were presented as:

- 1.5 meters above bottom - $453; and
- 3.0 meters above bottom - $1,617

4.2.1.1.3.4 Sediment Removal/Replacement

Krebs and Tanner (1981) report on the costs of sediment removal in conjunction with an oil discharge in the Potomac River near the mouth of the Chesapeake Bay. Removal was accomplished by a track-mounted Gradall tractor with a one cubic yard bucket. The stripped area was in a narrow fringing saltmarsh. The substrate was stripped to a depth of 20 centimeters.

Costs per square meter of stripped area (in 1992 dollars) are as follows:

Removal	$3.75
Disposal of stripped material	$2.27
Subtotal for removal alone	$6.02
Backfilling	$1.91
Total including backfilling	$7.93

Plant propagation costs would be additive to the above figures. Replanting costs would be similar to those in the discussion under Replanting.

4.2.1.1.3.5 Vegetation cropping

American Petroleum Institute (1991) provides estimates of the cost requirements for vegetation cropping. These are professional estimates based upon a composite of actual instances of vegetative cropping after oil discharges. The reported cost estimate is based on the following. It was assumed that a four person crew could crop 585 square meters of vegetation per day. The crew was provided with two small boats. The cost per day was estimated as follows:

• Labor - 32 person-hours	@ $35 per hour	$1,120
• Boats - 2 boats	@ $100 per day	200
• Other - 40 percent of the labor and boat costs for miscellaneous equipment and supplies, disposal of oiled debris, and contingency		528
• Total Cost Per Day		$1,848

Under the assumption that this crew could crop 585 square meters per day, the estimated cost for vegetative cropping was $3.16 per square meter.

4.2.1.1.3.6 New Saltmarsh Creation

Costs of creating a new replacement saltmarsh are highly variable. Efforts can range from simple breaching of a dike to inundating a previously drained area to extensively planned efforts involving considerable site excavation. The costs are extremely site sensitive. Every degraded saltmarsh has unique features that pose a challenge to the design of a created saltmarsh.

Factors that can affect the costs include those related to the specific characteristics of the site as well as the features that the designers may wish to include. A partial list of these may include:

- The basic wetland creation method that is being employed (i.e., dike breaching, dredge spoil disposal, etc.);
- The costs involved with acquiring a site. Some sites may have public status and acquired for free while other sites may still be privately owned;
- The costs of the specific design. As with consumer products, the "quality" can range from basic to deluxe. In one project, planning for a specific site resulted in engineering cost estimates that ranged from $5 to 28 million depending on the action that was being considered;
- The amount of excavation work that is required to bring the substrate to the proper level with respect to the tide. When soils are drained, they subside over time;
- The degree of channelization within the designed marsh area. This relates to the degree of intricacy incorporated into the design;
- The distance to a source of water for the tidal flows;
- The topography that must be crossed by the access channels or conduits on their way to the source of tidal water;
- The tidal characteristics at the site;
- The number of dike breaches, conduits, or tide gates that will be required to obtain an appropriate tidal flow;

- The degree to which it is necessary to remove contamination from the site. Many degraded saltmarshes are in areas that are seriously affected by urban, agricultural, or industrial development;

- The amount of litter and debris that must be removed from the site;

- The degree to which it is necessary to remove remnants of old buildings, equipment or other forms of development. Future restoration of a 100 hectare urban saltmarsh in Los Angeles is estimated to cost $10 to $50 million because a major roadway must be relocated (National Research Council, 1992);

- The degree to which materials must be added to the soil to yield the desired characteristics;

- The method of vegetation (i.e., natural, seeding, transplanting, etc.);

- The spacing of vegetation within planted areas;

- The proportion of planted, unplanted, and open water areas within the overall design; and

- The efforts that are required to control exotic species.

Exhibit 4.3 summarizes some costs of typical wetland creation projects. The reported costs for these projects have been adjusted to 1992 dollars. The cost figures presented here are for projects that had either no or minimal planting. Thus, planting costs would be in addition to the costs presented here.

The costs presented in Exhibit 4.3 ranged from $485 to over $70,000 per hectare. The costs presented here have a wide range yet they not represent the extremes. Restoring some wetlands in urban areas was estimated to cost considerably more. The actual cost estimates for a specific site would have to be based on preliminary engineering and biological site surveys.

Exhibit 4.3 Typical wetland creation costs.

Reference Number	Size (hectares)	Cost (1,000 dollars per hectare)	Restoration Method
1	235	843	Dredge disposal with minimal planting
2	272	6,490	Dredge disposal and excavation with minimal planting
3	309	6,480	Dredge disposal and excavation with minimal planting
4	40	9,424	Dredge disposal with minimal planting
5	371	2,429	Tidal gates and regrading
6	91	5,211	Excavation and dike breaching
7	247	17,414	Dredge disposal
8	556	2,675	Excavation and dike breaching
9	32	21,607	Excavation and tidal gate
10	15	18,237	Excavation and dike breaching
11	37	12,010	Excavation; flooding problems encountered
12	383	1,722	Excavation and water control structures
13	543	485	Minimal excavation
14	8	70,560	Dredge disposal and protective structures
15	8	41,160	Dredge disposal
16	5	17,854	Dredge disposal
17	2,470	2,247	Excavation and tidal gate
18	2,470	12,583	Excavation and tidal gate
19	287	27,119	Excavation and tidal gate

Source: Josselyn, 1982; Army Corps of Engineers, 1978; Josselyn et. al. 1991; Purcell and Johnson, 1991.

4.2.1.1.3.7 Low Pressure Flushing

American Petroleum Institute (1991) provides cost estimates for flushing in a marsh including recovery of oil. The cost per hectare was estimated as follows:

Labor - 247 person-hours @ $35 per hour	$ 8,645
Equipment and supplies (10% of labor)	865
Contingency - additional 20 percent	1,902
Total cost per hectare	11,412

4.2.1.1.3.8 Bioremediation

See Section 4.2.6.1.3.5 for a discussion of bioremediation costs.

4.2.1.2 Mangrove Swamp

This section presents a review of the costs associated with each technically feasible restoration option discussed in Section 2.2.1.2 for affected mangrove habitats. These restoration actions include the following:

- Natural Recovery;
- Selected Replanting;
- Construction of Channels for Flushing; and
- Low Pressure Flushing.

4.2.1.2.1 Oil Related Literature

Based on a review of existing literature on techniques for mangrove restoration due to oil related injury, the actions identified above were discussed as technically feasible. With the exception of the channel opening each action was demonstrated in previous restoration projects (Ballou and Lewis, 1989; Getter et al., 1984; Goforth and Thomas, 1979; Lewis, 1979; Lewis, 1981; Lewis, 1990; Teas, 1981; Teas et al., 1989; Thorhaug, 1989).

4.2.1.2.2 Non-oil Related Literature

Injury also occurs to mangrove habitats from natural occurrences and non-oil man-induced impacts. Costs related to the restoration of habitats altered by such impacts are reported in the literature and describe projects which employ different replanting techniques. These historical mangrove restoration projects include those discussed by Teas (1979), Goforth and Thomas (1980), and Sosnow (1986).

4.2.1.2.3 Costs of Restoration Actions

4.2.1.2.3.1 Natural Recovery

Costs of monitoring programs are discussed in Section 4.4.

4.2.1.2.3.2 Replanting

The types of plant material commonly used for mangrove restoration include mangrove propagules, seedlings, or young mangrove trees. The replanting process is typically performed manually using planting material which is either purchased from local nurseries or collected from a healthy adjacent mangrove area.

Unit costs of mangrove restoration projects were derived from several sources which demonstrate alternative planting techniques from mangrove restoration projects that used different types of planting material. As shown in Exhibit 4.4, these sources provide cost estimates for the purchase and/or gathering of planting material and the planting of mangrove propagules, seedlings, and young mangrove trees. The cost sources were derived in different years and thus adjusted using the GNP price inflator to reflect costs in mid-1992 dollars.

4.2.1.2.3.2.1 Propagules

Mangrove propagules are fresh seeds picked from mature fruits on trees in an established mangrove community. Propagules can also be collected from shorelines, but must exhibit characteristics of a propagule recently released from a mature fruit.

The estimated unit costs associated with replenishing mangroves through propagule dispersion for oil-injured habitats using collected or purchased propagules were extracted from various sources in the literature. Lewis (1981) and Thorhaug (1989) both report costs from historical restoration projects where propagules were planted for mangrove restoration. In these oil related restoration projects (Lewis (1979); and Mangrove Systems, Inc. (1980)), collected propagules for planting were used for restoration of injured red mangrove trees. When propagules are collected, they are generally picked from young buds on mangrove trees or collected from the shoreline. Costs for performing the mangrove transplants using collected

Exhibit 4.4 Reported costs for mangrove restoration ($/ha ($/m^2) in mid-1992 dollars).

Mangrove Type and Planting Technique	**Spacing (m)**			**Source**
	0.30	**0.61**	**0.91-1.23**	
Seeds (collected) Red Mangroves	$21,376 ($2.14)	$5,190 ($0.52)	$2,395 ($0.24)	Teas, 1977 (In: Lewis, 1981; Thorhaug, 1989)
	- - -	- - -	$11,301 ($1.13) $22,604[1] ($2.26)	Lewis, 1979 (In: Lewis, 1981; Thorhaug, 1989)
	$24,712 ($2.47)	$5,272 ($0.53)	$2,471 ($0.25)	Mangrove Sys. Inc., 1980 (In: Lewis, 1981)
Seeds (purchased) Red Mangroves	$23,637 ($2.36)	$5,761 ($0.58)	$2,649 ($0.26)	Teas, 1977 (In: Lewis, 1981; Thorhaug, 1989)
	$26,359 ($2.64)	$5,766 ($0.58)	$2,636 ($0.26)	Mangrove Sys. Inc., 1980 (In: Lewis, 1981)
Seedlings (purchased) Red, Black and White Mangroves	$47,059 ($4.71)	$11,345 ($1.13)	$5,273 ($0.53)	Teas, 1977 (In: Lewis, 1981; Thorhaug, 1989)
	$177,254 ($17.73)	$44,863 ($4.49)	$19,939 ($1.99)	Mangrove Sys. Inc., 1980 (In: Lewis, 1981)
Seedlings Red Mangroves	- - -	- - -	$42,328 ($4.23)	Sosnow, 1981
3-Year-Old Trees (purchased) Red, Black and White Mangroves	- - -	- - -	$454,055 ($45.40)	Teas, 1977 (In: Lewis, 1981; Thorhaug, 1989)
	- - -	- - -	$115,321 ($11.53)	Mangrove Sys. Inc., 1980 (In: Lewis, 1981)
3-Year-Old Trees (transplanted) Red Mangroves	- - -	- - -	$82,072 ($8.21)	Goforth and Thomas, 1979 (In: Lewis, 1981)

[1] Actual cost of a full-scale commercial restoration project.

propagules were reported in Mangrove Systems, Inc. (1980) and differ based on the spacing requirements for various planting scenarios. Restoration costs for propagule planting using collected seeds range from $2.47 per square meter for 0.3 meter spacing to $0.25 per square meter for approximately 1.0 meter spacing (in mid-1992 dollars). In Lewis (1981), collected red mangrove propagules were transplanted at a cost of $1.13 per square meter for 1.0 meter spacing. Lewis (1981) also reports costs for mangrove restoration using purchased propagules for transplant projects.

Restoration costs using purchased propagules range from $2.64 per square meter for 0.3 meter spacing to $0.26 per square meter for 1.0 meter spacing. The estimated unit costs associated with replenishing mangroves through propagule dispersion for non-oil injured habitats, using collected or purchased propagules, were extracted from various sources in the literature. Teas (1977) presents the costs of propagule planting for different spacing requirements, and estimates costs of collected propagules to range from $0.24 per square meter for plants spaced at about 1.0 meter to approximately $2.14 per square meter for 0.3 meter spacing. Lewis (1981) and Thorhaug (1989) both report similar costs. Restoration costs for propagule planting using purchased seeds range from $0.26 per square meter for 1.0 meter spacing to $2.36 per square meter for 0.3 meter spacing. Restoration costs using mangrove propagules are summarized for each mangrove type and planting action in Exhibit 4.4.

4.2.1.2.3.2.2 Seedlings

Mangrove seedlings used as transplant material are generally grown to a specific size or age in nursery conditions before being planted. The growth of fresh seeds to an average height of 0.5 meters with some leaves present is generally considered suitable for planting material. Seedlings with these physical characteristics range from 6 to 18 months in age.

The literature on oil related mangrove restoration, found in Lewis (1981), reports costs from one restoration project where 6-month old red, black, and white mangrove seedlings were used for mangrove transplants (Mangrove Systems, Inc., 1980). The cost of restoration projects using purchased seedlings range from $17.73 per square meter for 0.3 meter spaced transplants to $1.99 per square meter for 1.0 meter spacing.

Costs for non-oil related mangrove seedling transplants are summarized below. Teas (1977) also reports costs for seedling transplants, estimated to range from $0.53 per square meter for 1.0 meter spacing to $4.71 per square meter for planting seedlings at 0.3 meter spacing. Other reported costs for seedling plantings for mangrove restoration due to dredging impacts include those presented by Sosnow (1986). Costs were derived for a full scale pilot restoration project in which 0.32 hectares of mangroves were restored. Adjusted to reflect costs for one hectare of mangrove habitat, project costs were estimated to total $42,328 or $4.23 per square meter of area restored. These costs reflect all costs associated with obtaining plant material and planting activities, land preparation, and rip-rap replacement (Sosnow, 1986). Costs for seedling transplants are also summarized in Exhibit 4.4.

4.2.1.2.3.2.3 Young Mangrove Trees

Young mangrove trees are generally grown in nurseries to approximately 1.0 meter in height and provide more rapid growth as transplant material to help with substrate stabilization. Use of 1.0 meter trees is more costly, as documented by past restoration experiments, but survival of transplants is generally greater, especially under stressful habitat conditions such as increased wave energy. Two studies in the literature tracked the costs of past mangrove restoration projects which used young trees for transplant material. Lewis (1981) summarizes the work of Mangrove Systems, Inc. (1980) and identifies the costs of the respective mangrove restoration projects. Restoration costs for mangrove restoration using three-year-old trees as transplants (at 1.0 meter spacing) were reported to be approximately $11.53 per square meter. A more recent analysis of mangrove restoration criteria notes that direct restoration of injured large mangrove trees with nursery-raised replacements is "prohibitively expensive." Costs to grow a single red mangrove tree to 5 meters in height (4 square meter coverage) including installation were estimated to be in excess of $11,000 (Crewz and Lewis, 1991). The higher cost of transplanting older, more mature mangrove trees relative to propagules and seedlings may be a result of the decreased availability of suitable donor trees and high costs of nursery supplied plant material.

Mangrove restoration using young mangrove trees (one to three years old) for transplant material was also been documented in the literature as suitable material for long-term restoration success for non-oil related injury (Goforth and Thomas, 1979; Teas, 1977). Two studies in the literature tracked the costs of past mangrove restoration projects (non-oil related) that used young trees for transplant material. Teas (1977) estimates costs of nursery-grown three-year-old trees to be nearly $74.00 each (adjusted for inflation). The costs for planting these trees at a spacing of 1.23 meters is estimated to cost approximately $454,000 per hectare, or $45.40 per square meter. Goforth and Thomas (1979), as reported in Lewis (1981), estimated costs of planting small mangrove trees for shoreline stabilization to be $82,000 per hectare, or approximately $8.20 per square meter. The costs for mangrove restoration using young tree transplants are also summarized in Exhibit 4.4.

It is important to note that all costs reported for each type of restoration project were incurred during small-scale restoration experiments where associated costs for profit and overhead were excluded. Depending on what plant material is used, a balance must be struck between cost, expected success, and time lapse until the planting is mature. The cost of replanting varies depending on the plant material used and spacing of the installations. It is apparent that for a given spacing distance, the costs increase substantially from the lower end (using propagules) to the higher end (using larger trees). For this reason, spacing is a critical factor when planning a restoration project. Reducing the spacing by a distance of one-third (from 0.91 meter to 0.61 meter), for example, more than doubles the number of installations required.

In addition, the need for other cost-generating components in a restoration project, such as surveys, meetings with regulatory agencies, and travel, may increase the costs of the restoration project considerably. Lewis (1979) identifies costs associated with a full-scale commercial restoration project where these components were included in the total cost of the project. In this case, the estimated cost per square meter of mangrove habitat restored (using collected propagules) was reported to be $2.26 per square meter, twice the costs of propagule planting alone.

For any completed replanting operation, a monitoring program should be developed in order to track the progress and reliability of habitat restoration. There were no reported costs in the literature for monitoring programs associated with any of the documented mangrove restoration projects. However, cost estimates of a generic monitoring program can be found in Section 4.4.

4.2.1.2.3.3 Construction of Channels for Flushing

No cost data were reported in the literature for mangrove restoration involving the opening and flushing of channels to circulate and dilute remaining concentrations of the pollutant. However, engineered estimates can be derived based on the expected costs of activities that comprise this restoration action. Cost estimates could be derived based on the level of effort necessary to excavate a designated mangrove habitat. These estimates would be based on such factors as required labor, materials, and equipment mobilization/demobilization.

According to Ballou and Lewis (1989), excavation of channels into an affected area would be a relatively expensive and complex task compared to other restoration actions (i.e., natural recovery and replanting).

4.2.1.2.3.4 Low Pressure Flushing

See Section 4.2.1.1.3.7.

4.2.2 Freshwater Wetlands

This section is divided into the emergent shrub and forested wetlands.

4.2.2.1 Emergent Freshwater Wetlands

Section 2.2.2.1 discusses the technical feasibility of emergent wetland restoration actions, which include the following:

- Natural Recovery;
- Replanting;
- Sediment Removal/Replacement;
- Vegetation cropping;
- New Wetland Creation; and
- Low Pressure Flushing.

Costs of the actions are discussed in the following sections.

4.2.2.1.1 Oil Related Literature

Although two reports addressing wetlands restoration following oil discharges were identified in Section 2.2.2.1.1 (Foley and Tresidder, 1977; and Pimentell, 1985), no information was identified regarding costs or economics of emergent wetlands restoration efforts in response to an oil discharge. Much of the literature regarding saltmarsh restoration may be directly applicable (see Section 3.2.1.1), although it should be noted that freshwater marsh plant diversity is typically much higher than that of saltmarshes, adding to the complexity, and therefore cost, of accomplishing a successful restoration.

4.2.2.1.2 Non-oil Related Literature

No information was identified regarding costs of restoration of emergent wetlands following discharges of hazardous materials. The following information on restoration costs is related to creation of wetlands, primarily on old mine lands, dredge disposal areas, or previously drained wetland being returned to marshland from agriculture.

4.2.2.1.3 Costs of Restoration Actions

4.2.2.1.3.1 Natural Recovery

Costs of monitoring programs are discussed in Section 4.4.

4.2.2.1.3.2 Replanting

Landin (1990) in a discussion of emergent wetland creation states that "marsh propagation costs will be determined by the labor and expense of obtaining, transporting, handling, storing, and planting propagules, the number of propagules required, any soil treatments necessary such a fertilization, and maintenance efforts."

<u>Labor requirements for replanting</u> - Labor costs for general (no specific species) planting activities are shown below. Additional labor costs are presented in Section 4.2.1.1.3.2, regarding replanting saltmarshes.

Source	**Activity (at 0.9 meter centers/intervals)**	**Person hours per hectare**
Landin, 1990	Digging, preparing, and planting transplants	98.7-198
Landin, 1990	Landin, 1990 Transplanting rhizomes, tubers, and rootstock	98.7-148
Landin, 1990	Seeding	10-40
Ternyik, 1978	Digging and planting "Tufted Hairgrass" in sandy material using professional nursery work force	86
Knutson, 1977	Excavating, separating, and planting "sprigs"	123
Knutson, 1977	Prepare and plant plugs	1,111
Knutson, 1977	Seeding, including "harvest, storage, dispersal	62
Dodd, Webb, 1975	Hand dig, separate, and transplant propagules	111-289

Landin (1982) reported that activities requiring plantings at 0.9 meter (1 yard) intervals will require roughly 9,900 plants per hectare. A 0.45 meter spacing will require four times as many plants per hectare, and, therefore, four times the labor. Plants set at 1.8 meters will require half the number of plants per hectare, and, therefore, half the labor hours. Values in the table above may be adjusted appropriately. Landin also points out the following:

Marsh propagation costs will be extremely site specific and will reflect such factors as logistics, man-hours costs, efficiency, plant design, and the texture of the substrate. The data reported here (see Landin, 1982, estimates above) are developed from sites that could support conventional equipment. Should the substrate of the site be poorly consolidated fine-textured material, more person power will be required to propagate due to "trafficability problems."

Estimates of total planting costs - Lee et al. (1976) estimated the cost of establishing two month old plant species at a density of 12,400 per hectare to be the following:

Type of vegetation	**Range of costs (1992 dollars)**	**Average cost**
Naturally available vegetation	$10,927 to $13,826	12,376
Commercially available vegetation	$15,387 to $18,286	$16,836

Based on these estimates, costs for using commercially available vegetation will run approximately 36 percent higher than vegetation available naturally for transplant.

Costs of Individual Plants - Marsh plants may be purchased at nurseries, although availability of many species may be limited. Some costs noted are as follows.

Source	Description	Per plant cost (1992)
Crabtree et al. (1990)	Purchasing and planting marsh plants	$0.98
Lee et al. (1976)	Purchasing and planting commercially available marsh plants	$3.03 (1)
Korschgen (1988)	Purchase price, winter buds of Wild celery	$0.12
Landin (1982)	Marsh plant purchase	$0.20 to 1.06

(1) Note that the value for commercial plants in 1976 was $1.36 per plant indexed to 1992 dollars to be $3.03. This calculation is made assuming that the value has moved only in response to inflation. In fact, the supply of commercially available marsh plants may have increased dramatically since 1976 in response to increased wetlands creation/restoration activities, in the process depressing prices in spite of inflation.

Using Muck as a Substrate and Seed Bank - Brown, Gross, and Higman (1984) studied the feasibility of placing peat as a substrate prior to revegetating as part of creating a wetland. As part of the study, they maintained detailed records of the number of loads, estimated volumes per load, round-trip travel time, and hours of equipment operation. Costs for two different peat placement operations are presented below.

Site: Activity	Machinery Used	Cost per m^3 (1992 dollars)
Site 1: Digging and transport	Cat 627 pans, D-8 Dozer, Motor Grader	$13.76
Site 1: Spreading	Komatsu Dozer	$1.89
Site 2: Digging and transport	Dragline, Payloader, and Dump truck	$2.28
Site 2: Spreading	D-3,D-5,D-6 Dozers	$4.52

The first site used Cat 627 scrapper pans to dig and transport the peat material and a dozer to spread the peat. At the second site, a dragline was used to excavate the material, 7.65 cubic meter (10 cubic yard) dump trucks were used for transport, and several large dozers were used to spread the peat. The general presumption by the authors was that small equipment may be more efficient than large equipment for this type of operation.

The cost for the acquisition of the peat is not included in the study. The peat reportedly was removed from "donor" swamps in forested wetlands that were to be mined. Obviously in cases where a donor site is not readily available for access to free peat, the cost of purchasing peat for transport to the site must be included.

The cost of incorporating a muck layer into the substrate (as described by Bacchus, 1989) were not broken out to allow an estimate of the cost of digging and transporting muck versus cost for grading, planting trees and herbaceous species, and project management. Cost per hectare were approximately $96 thousand per hectare for the entire restoration (1992 dollars).

4.2.2.1.3.3 Sediment Removal/Replacement

Sediment Removal - No cost estimates were identified in the literature regarding the cost of sediment removal from freshwater emergent wetlands. Krebs and Tanner (1981) reported the costs of sediment removal following impacts of an oil discharge on a saltmarsh near the mouth of the Potomac River. The costs of removal were estimated at $6.02 (1992 dollars) per square meter for removal and backfilling costs of $1.91 for a total of $7.93 (see Section 4.2.1.1.3.4 for details).

Crabtree et al. (1990) reported the costs of "spreading topsoil," or mulching as the activity is commonly described. The activity is typically employed for replanting purposes as the mulch is full of seeds, roots, and rhizomes. The unit costs are presented below.

Activity	Cost (1992 dollars)
Cost of excavating topsoil	$5.70 per cubic meter
Cost of spreading topsoil	$3.05 per square meter
Total cost for 15.2 centimeter (6 inch) layer	$3.84 per square meter

4.2.2.1.3.4 Vegetation Cropping

Foley and Tresidder (1977) and Pimentell (1985) both reported on the technical feasibility of cropping vegetation. Neither report, however, discussed the costs of this type of operation. The American Petroleum Institute (1991) estimates the costs of vegetative cropping of saltmarshes at $3.16 per square meter (costs and assumptions are described in Section 4.2.1.1.3.5).

4.2.2.1.3.5. New Wetland Creation

Diking/plugging drains - Reclaiming previously drained wetlands in many cases is a simple matter uf plugging the fixture that was installed to drain the water off the area (Piehl, 1986; Rondeau, 1986; Kusler, 1986). Kusler et al. (1986) reported that 'the cost to restore small wetlands with a single dike averages' $373 per wetland (1992 dollars). On these wetlands the drain is diked with a plug on average that is "4 feet high, 10 feet wide, and 45 feet long with the face of the dike reshaped to the contours of the wetland basin." On larger wetlands areas, water control structures are incorporated into the dike, the costs for these range from $1,864 to $12,430 each (1992 dollars). Rondeau (1986) reported plugging a tile and ditch drainage structure for a cost of $323 (1992 dollars). At a different area the author discussed the creation of seven wetland basins for an average cost of $430 per wetland (1992 dollars). The author reported maintenance costs (actually costs paid to farmers to conduct weed control) of $235 per hectare per year. Piehl (1986) reported similar annual expenditures of $222 per hectare (1992 dollars).

Examples of Total Costs - Total costs for selected freshwater emergent wetland restoration/creation operations are as follows:

Source and Project	Activities	Cost per hectare (1992 dollars)
Crabtree et al. (1990); (French Creek)	Cleared, excavated, graded, returned topsoil, planted with nursery stock	$23,578
Lee et al. (1976)	Planted naturally available vegetation at 12,400 plants per hectare (no construction costs)	$12,376
Lee et al. (1976)	Planted commercially available vegetation at 12,400 plants per hectare (no construction costs)	$16,836
Crabtree et al. (1990)	Total cost for mulching using a 15.2 centimeter (6 inch) layer (no grading or planting costs are included)	$38,370
Crabtree et al. (1990) (Rancocas Creek)	Revegetated by planting (construction costs not included)	$28,908

4.2.2.1.3.6 Low Pressure Flushing

See Section 4.2.1.1.3.7.

4.2.2.2 Scrub-Shrub Wetland

No cost data for restoration of scrub-shrub wetlands was identified. Costs of equivalent emergent and/or forested wetlands (i.e., same species composition) give an indication of the potential costs.

4.2.2.3 Forested Wetlands

Section 2.2.2.3 discusses the technical feasibility of forested wetland restoration actions including the following:

- Natural recovery;
- Replanting; and
- Forested Wetland Creation.

4.2.2.3.1 Oil Related Literature

No information was identified on restoration efforts in response to an oil discharge.

4.2.2.3.2 Non-oil Related Literature

Little was published addressing restoration of forested wetland. The following information on restoration costs is related to creation of wetlands, primarily on old mine lands or dredge disposal areas.

4.2.2.3.3 Costs of Restoration Actions

4.2.2.3.3.1 Natural Recovery

Costs of monitoring programs are discussed in Section 4.4.

4.2.2.3.3.2 Replanting

In practice, replanting in response to discharge impacts may follow vegetation removal or soil removal/replacement. In the literature no discussion of remediating discharge impacts on forested wetlands was noted. The cost discussion below is related to replanting of trees during the creation of wetlands. These costs are referenced in New Wetland Creation, but should be applicable to replanting as part of a mitigation restoration effort.

Transplanting Seedlings - Hammer (1992), in his book Creating Freshwater Wetlands, discussed the costs of nursery grown plants as reported below.

Type of Nursery grown plants	Cost per plant (1992 dollars)	Comments
Potted materials	$1.00 to $3.00	Easily planted, suffer less transport and planting shock
Bare-root seedlings	$0.25 (or less)	Susceptible to transport planting shock
Containerized seedlings (in trays, molded peat or wood cups)	$0.50-$0.75	May survive in sites too harsh for bare-root seedlings
Bagged (root-ball) saplings	$3.00 to $50.00	Less susceptible to transport planting shock

These costs do not reflect costs of planting or maintaining the seedlings/saplings or preparing the substrate.

Landin (1982), in discussing the creation of a wetland on a dredge disposal site in Texas, noted that generally, 111 to 222 person hours per hectare should be allowed for "digging, preparing, and planting transplants on a site." The author noted that the habitat development (planting) aspects of the Trinity River project could be carried out for about $5,323 per hectare (1992 dollars). This reportedly entailed planting trees at 3.05 meter (10 foot) intervals and herbaceous species at 0.9 (3 foot) meter centers. The costs do not include, however, diking of the dredge spoil area or any contouring or other ground moving.

Weston and Brice (1991) reported on replanting of indigenous species following removal of exotic pest species. The 1.0 hectare swamp area and 0.2 hectare ponded area were planted with 228 trees and shrubs. The trees, purchased at a local, native-plant nursery, were planted in 3-5 gallon root balls while shrubs were planted in one gallon root balls. Total costs for the plants (both trees and shrubs) were $1,243; the labor used was from a non-profit organization at an hourly rate of $9.82 per hour (1992 dollars).

Denton (1990) in a report regarding using cyprus at forested mitigation sites, estimated costs for installation, monitoring, and maintenance of forest mitigation areas. The costs were reported as $5.32 for small trees with roots filling a 1-gallon can, $7.45 for 3-gallon trees, and $23.41 for 7-gallon trees (1992 dollars). Maintenance costs were estimated at $6,567 per hectare for the first two years, $4,728 per hectare the third year, and $3,153 per hectare thereafter (1992 dollars). The author estimated monitoring costs at $2,890 per hectare per year. In estimating total costs the author took into account differences in planting small versus large plants, their cost differences, and, assuming a goal of 33 percent canopy was to be achieved, calculated costs and time to achieve canopy cover. The author estimated that "planting small trees (1-gallon) densely at 2,470 per hectare and monitoring until a 33 percent canopy cover is attained will require 5 years" at an estimated cost of $51,753 per hectare in 1992 dollars. The author contrasted that strategy by estimating that planting larger (7-gallon) trees less densely at 990 per hectare (400 per acre) will require 7.5 years at an estimated cost of $76,844 per hectare in 1992 dollars. The author concludes that the former strategy is cheaper, faster, and a good opportunity to "create a wetland with trees as dense as those found in many natural wetland systems."

Transplanting With a Tree Spade - Posey et al. (1984) reported the technical feasibility of replanting adult trees 9 meters or less in height. The trees were transplanted using a Big John 78 Tree Spade capable of handling a 3400 kilogram ball 2 meters in diameter. Accurate records were reportedly kept indicating sizes and quantities transplanted as well as survival rates and regeneration statistics. The cost of this spade transplant was $72 to $85 per tree or approximately $9,847 per hectare in 1992 dollars (no planting density was provided). No cost was included for purchase of the trees themselves as the trees were on a plot of land scheduled to be cleared for strip mining. Obviously in cases where a donor site is not readily available for access to free trees, the cost of purchasing trees for transport to the site must be included.

Transplanting Using Boxing - Carothers et al. (1990), in an appendix to their study on restoration of riparian lands, noted that "mature trees of any size can be boxed and moved." They note that while this action was used to salvage trees in areas to be developed, the action has not been used in restoration or creation projects. They state that "in some cases this technique (action) may be useful," but they note that its cost is "its main drawback." The authors' estimates were reportedly $532 to $1,064 per tree in 1992 dollars. They discussed one case in Arizona where 240 trees were salvaged (boxed and removed) from a 13 acre (5.27 hectare) riparian woodland. They reported the costs as high, ranging from $53.20 to $85.12 per basal diameter inch (2.54 centimeters) (1992 dollars) with an "additional 40 percent of this cost required to replant and maintain in a nursery."

Revegetation Using Cuttings - One case study on a wetland created in Idaho reported that ten to twenty of the unrooted cuttings reportedly could be planted with the same effort and expense of one rooted cutting (Jensen and Platts, 1990). However, survival rates of unrooted cuttings would be much lower, so that the total expenses of replanting would not be as low as this suggests.

Revegetation Using Seeds - In a report discussing seeding with oak acorns, Johnson and Krinard (1987) collected information regarding cost, seed handling, planting methods, survival, growth, and competition of using acorns to revegetate with oaks. They found the costs for the collection of acorns to be $59.51 per hectare ($24.10 per acre) planted. The authors, estimated an additional cost of $5.95 to $14.89 per hectare ($2.41 to $6.03 per acre) if the seeds were stored one year (1992 dollars). They further noted that "total cost of establishment by direct seeding, including collection and handling of seeds, labor, and site preparation," may range from $35.70 to $148.77 per hectare ($14.46 to $60.25 per acre) in 1992 dollars.

McElwee (1965) discussed the advantages and disadvantages of direct seeding of hardwoods in river bottoms. In terms of cost, the author indicated cost savings of 25 to 33 percent over hand planting seedlings, which, the author notes, is often required because the saturated soils prohibit the use of mechanical planting.

4.2.2.3.3.3 Forested Wetland Creation

Most of the costs related in the previous actions were incurred or estimated during the creation of new wetlands. Included below are several restoration projects for which costs were not broken-out by the various aspects of the effort (i.e., replanting versus ground preparation).

One wetland creation project in central Florida was characterized by the inclusion of a muck layer into the substrate followed by planting with 10 species of trees and 9 herbaceous species (Bacchus and Webb, 1989)). The cost of the entire wetland creation project was $493,742 for the 5.1 hectare area, or $96,812 per hectare in 1992 dollars.

Haynes and Crabill (1984) reported that from 90 to 95 percent of the total cost of reclaiming 6.5 hectares of phosphate-mined lands as forested wetlands were for "earthmoving work involving heavy equipment." Revegetation of the project site was estimated to be 2-3 percent of the total reclamation cost while monitoring was 1-2 percent of the total cost.

In practice, dead trees and other affected vegetation may be removed to reduce the oil or other hazardous material residue remaining on the vegetation. In the literature, no discussion of remediating discharge impacts on forested wetlands was noted. Weston and Brice (1991) reported on the technical feasibility of removing exotic, unwanted species from a wetland site prior to replanting with indigenous species. The one hectare "low swampy area" required 664 hours of labor for a total of $6,576 (1992 dollars) to cut the trees with a chain saw and haul the trees out by hand. The labor was supplied by a non-profit organization, a residential treatment facility for adjudicated youth. The authors stated their belief that this use of non-profit labor had "particular applicability to other habitat restoration projects." Tipping fees for hauling the unwanted slash were $3,580 and the cost for chemicals to treat the stumps and unwanted vegetation was $1,585 (1992 dollars). The area restored was one hectare, so by definition, all costs reported are per hectare unit costs. The trees removed in the Weston and Brice study were a small, understory-type species known as Brazilian Pepper. Removal of large trees such as cyprus and red oak would require a full-scale timber operations using mechanical skidders to haul out timber and logging trucks with lift arms to pick up and remove the logs. Costs for these operations were not available in the literature regarding forested wetlands restoration.

4.2.2.4 Bogs and Fens

No cost data for restoration of bogs and fens was identified.

4.2.3 Vegetated Beds

4.2.3.1 Macroalgal Beds (Estuarine and Marine)

4.2.3.1.1 Intertidal Macroalgal Bed

No cost data were identified for replanting of intertidal macroalgal beds. Other restoration actions for this habitat would be as described for rocky or cobble-gravel shores (Sections 4.2.6.1 and 4.2.6.2).

4.2.3.1.2 Kelp Bed

Section 2.2.3.1.2 discusses the technically feasible restoration actions identified for injured kelp bed habitats. These actions include:

- Natural Recovery;
- Replacement with Transplants; and
- Vegetation Cropping.

This evaluation was based on a review of available literature as discussed below.

4.2.3.1.2.1 Oil Related Literature

As discussed in Section 2.2.3.1.2, no literature exists that documents actual restoration activities performed for oil-injured kelp habitats. Similarly, there exists no documented costing information for oil related restoration actions performed for kelp habitats.

4.2.3.1.2.2 Non-oil Related Literature

Actual costing information reported in the literature for restoration actions performed on kelp habitats after non-oil related injury was identified in two cases. The first was reported in a report prepared for the California Department of Fish and Game (CDFG) by Kelco Co., a primary commercial harvester of kelp (CDFG, 1990). Costs reported in this document are related to restoration activities performed on California kelp beds using three restoration techniques: use of artificial growth centers (AGCs), use of AGCs with kelp transplants, and stapling loose plant material to the habitat bottom.

The second case where costing information was reported was found in Shiel and Foster (1991). This paper discusses a range of historical restoration activities performed on kelp habitats and documents only one instance where related costs were reported. The reported costs are those related to the above-mentioned restoration actions performed by Kelco Co., as reported in CDFG (1990).

No literature on the costs of restoring other than *Macrocystis* kelp beds (e.g. *Laminaria*) were found. This section will, thus, only review costs of *Macrocystis* restoration efforts.

4.2.3.1.2.3 Cost of Restoration Actions

4.2.3.1.2.3.1 Natural Recovery

Costs of monitoring programs are discussed in Section 4.4.

4.2.3.1.2.3.2 Replacement with Transplants

Three technically feasible restoration alternatives for restoration of kelp beds include the placement of artificial growth centers (AGCs) into the habitat to induce natural colonization, placement of artificial growth centers with transplants for accelerated recovery, and stapling of loose kelp plants to the habitat bottom to increase the habitat cover. The reported costs for each of these activities separate restoration costs into two primary components. Costs related to the fabrication of materials used and costs of material deployment to the injured habitat. The costs associated with each of these restoration actions are summarized in Exhibit 4.5 and described below.

4.2.3.1.2.3.2.1 Artificial Growth Centers

The use of artificial growth centers as a restoration action involves the placement of "mushroom" anchors on the habitat bottom to act as a surrogate substrate for natural macroalgal spore colonization. The anchors are constructed of concrete with two rebar "handles" set into the flat surface of the anchor to support plant attachment. Mushroom anchors are deployed into the water by the use of small boats or larger vessels, depending on the acreage cover desired for one day's deployment.

Cost estimates developed by Kelco Co. (CDFG, 1990) for a restoration project performed in the Santa Barbara, California area include unit costs for all components of the restoration project, such as the level of effort required for anchor fabrication, anchor deployment, and shipping. These cost components are identified in Exhibit 4.5. Total costs to restore one hectare of kelp bed were estimated at $1,546 adjusted to reflect costs in mid-1992 dollars.

4.2.3.1.2.3.2.2 Artificial Growth Centers with Transplant Material

This action also involves the use of the "mushroom" anchors described above, with attached plant material. The cost components associated with this method are similar to those used for artificial growth centers, with the exception of additional costs for nursery-grown macroalgal plant material. The use of transplant material significantly increases the cost of restoration per unit of habitat restored, as shown in Exhibit 4.5.

The restoration project performed by Kelco Co., as described above (CDFG, 1990), also performed kelp restoration using artificial growth centers with attached transplant material. The costs for this action are higher per acre of coverage due to the increased cost of transplant material and additional labor and materials required to handle and attach the plant material. Total costs for the use of artificial growth centers with transplants were reported to be $3,142 per hectare of kelp habitat restored.

4.2.3.1.2.3.2.3 Staple Loose Plants to Habitat Bottom

The third action for kelp transplants involves the stabilization of loose kelp plants. A demonstrated method of performing this action, as documented by Kelco Co.'s restoration efforts (CDFG, 1990), involves the stapling of loose plants to the habitat bottom through the use of large (two foot long) rebar staples with hose "barbs" attached to the ends. Two staples are used to secure one loose plant. Unlike the vessel deployment of the anchor transplants, the stapling method requires the use of divers. The staple method is generally used in areas where the bottom substrate is soft, such as silt, mud, or sand. The cost components required for this method are summarized in Exhibit 4.5.

Efforts at using staples to stabilize a kelp habitat were based on a restoration project performed in a predominantly sandy environment. Costs for this method were lower than those described for anchors and anchor transplants, estimated at $1,833 per hectare. These costs reflect adjustments to mid-1992 dollars.

As mentioned above, the costs reported above for kelp restoration were identified from two literature sources, a report prepared by Kelco Co. for the CDFG based on actual restoration performed and an academic paper prepared on the status of kelp restoration (Shiel and Foster, 1991). This latter paper reported the costs from the restoration work performed by Kelco Co., thereby describing the same project. Shiel and Foster also noted that the restoration work performed by Kelco was the only documented project where restoration costs were specifically developed. Therefore, the costs reported may not be an accurate representation of a kelp restoration effort, due to the variability often observed in damage assessment. Also, the restoration actions were focused only on the kelp, not on restoring associated plant and animal species.

Exhibit 4.5 Reported costs for kelp bed restoration actions for non-oil-related injury ($/ha in mid-1992 dollars).

Cost Components	Restoration Technique		
	Artificial Growth Centers (AGCs)	**AGCs with Transplants**	**Stapling Loose Plants**
Fabrication:			
Materials	$452	$452	$430
Labor	252	252	42
Facilities	22	22	54
Deployment:			
Vessels	378	795	252
Labor	180	422	909
Travel	30	30	20
Miscellaneous	126	126	126
Harbor	32	64	--
Forklift	20	40	--
Shipping	54	40	--
Transplants	--	855	--
Total Cost	$1,546	$3,142	$1,833

Source: California Department of Fish and Game, 1990.

In addition, the reported costs did not address the costs associated with a monitoring program. For all types of restoration work, a monitoring plan should be developed in order to measure the reliability of the restoration effort. As described above for the natural recovery option, the monitoring program would be designed based on the objectives and standards of environmental recovery, depending on the nature and extent of injury.

4.2.3.1.2.3.3 Vegetation Cropping

No cost data were identified for vegetation cropping of kelp beds.

4.2.3.2 Seagrass Beds

This section provides cost estimates for restoration activities related to seagrass beds.

As identified in Section 2.2.3.2, technically feasible restoration actions for injured seagrass habitats include:

- Natural Recovery; and

- Replanting.

The following sections provide cost estimates of these actions as identified in the literature for historical restoration projects.

4.2.3.2.1 Oil Discharge Related Literature

As discussed in Section 2.2.3.2, there are no documented cases in the literature where seagrass beds were restored due to oil injury.

4.2.3.2.2 Non-oil Related Literature

Cost data for seagrass restoration is documented in several literature sources for restoration projects performed due to injury resulting from activities such as pipeline construction, coastal development, and natural occurrences. The following literature sources identify cost information related to historical seagrass restoration projects where replanting activities were performed: Fonseca et al. (1979); Phillips (1980, 1982); Thorhaug (1980); Fonseca et al. (1982b); Thorhaug (1986); Thorhaug (1989); Thorhaug and Austin (1976); Austin and Thorhaug (1977); and Fonseca et al. (1990b).

4.2.3.2.3 Cost of Restoration Actions

4.2.3.2.3.1 Natural Recovery

Costs of monitoring programs are discussed in Section 4.4.

4.2.3.2.3.2 Replanting

As discussed in Section 2.2.3.2 regarding the technical feasibility of seagrass restoration, several types of planting material can be used to replant injured seagrass habitats. The available cost information from historical replanting projects document cases where plugs and shoots were used as planting material. Exhibit 4.6 summarizes the cost information for each of these replanting techniques and identifies the source of data. The cost of seagrass per hectare (\$0.84 per m^2) to \$37,800 per hectare (\$3.80 per m^2). grass plugs range from approximately \$8,352 per hectare (\$0.84 per m^2) to \$37,800 per hectare (\$3.80 per m^2).

Costs for replanting seagrass habitats located in subtropical and tropical habitats are reported in the literature for transplanting activities using seedlings, plugs, and shoots. As discussed in Section 2.2.3.2., the most feasible restoration action for species of seagrass found in the subtropical zone is the use of seeds or seedlings as planting material for eelgrass for which seeds are available or can be collected. Seeding other seagrasses is more problematic since ample quantities of seeds do not appear to be available. Exhibit 4.7 summarizes the reported costs for this method and other techniques used in historical restoration projects. The cost range reported for seedling replanting varies widely, as reported by Thorhaug and Austin (1976). These data are widely reported in other sources as well. Costs for seedling replanting range from approximately \$93,337 per hectare (\$9.33 per m^2) to nearly \$622,277 per hectare (\$62.23 per m^2). These estimates reflect the higher end of reported costs, primarily due to the intensive labor and amount of materials required to achieve recovery goals. Thorhaug (1986) reports on another project where restoration using seedlings was performed. These costs were much lower, estimated at \$23,150 per hectare (\$2.32 per m^2). Only one restoration project reported costs using seagrass plugs, at a cost of \$200,232 per hectare (\$20.02 per m^2). Another, more recent source reported costs of experimental restoration activities where seagrass shoots were used. These materials were planted using three different methods: the staple, peat pot, and core methods. Costs for these methods were estimated to range from \$2.58 per m^2 to \$7.52 per m^2 (due to the small size of the project, costs were only reported for the area restored).

Exhibit 4.6 Reported costs for temperate seagrass (Eelgrass) restoration actions ($/ha ($/m^2) in mid-1992 dollars).

Replanting Technique	Cost	Source
Plugs	$37,800 ($3.78)	Robilliard and Porter, 1970 (In: Fonseca et. al. 1979; Thorhaug, 1986; Phillips, 1980, 1982)
	$8,352 ($0.84)	Ranwell et. al. 1973 (In: Fonseca et. al. 1979; Thorhaug, 1986; Thorhaug, 1980; Phillips, 1982)
	$11,713 ($1.17)	Churchill et. al. 1978 (In: Fonseca et. al. 1979; Thorhaug, 1986; Phillips, 1980, 1982)
	$33,464 ($3.35)	Goforth and Peeling, 1979 (In: Thorhaug, 1986)
Shoots with Woven Mesh Anchor Actual Projected	$ 31,771 ($3.18) $10,425 (1.04)	Fonseca et. al. 1979 (Also in: Thorhaug, 1986; Phillips, 1980, 1982)
Shoots	$42,480- $63,720 ($4.25-$6.37)	Fonseca et. al. 1982b

For eelgrass restoration using shoots, estimated costs range from $10,425 per hectare ($1.04 per m^2) to $63,720 per hectare ($6.37 per m^2). These costs reflect adjustments for inflation to show estimated costs in mid-1992 dollars.

Exhibit 4.7 Reported costs for subtropical and tropical seagrass restoration ($/ha ($/m^2) in mid-1992 dollars).

Replanting Technique	Cost	Source
Seedlings	$93,337[2] ($9.33) Cover of 3000 blades/m^2 in 2.5 years	Thorhaug and Austin, 1976; (Also in: Austin and Thorhaug, 1977; Phillips, 1980; Thorhaug, 1980; Thorhaug, 1989)
	$124,452 ($12.45) Cover of 4000 blades/m^2 in 2.5 years	
	$311,139 ($31.11) Cover of 1000 blades/m^2 in 0.8 years	
	$622,277 ($62.23) Cover of 2000 blades/m^2 in 0.8 years	
	$23,150 ($2.32)	Thorhaug, 1986
Plugs	$200,232 ($20.02)	Thorhaug, 1980
Shoots in Test Plots Using:		Fonseca et. al. 1990
Staple	($4.06-$4.40)	
Peat pot	($2.58-$3.18)	
Core	($7.52)	

[2] Costs reflect adjustment for additional cost components.

The range of cost estimates is broad due to several factors. First, planting sites and conditions vary for all types of injury, and restoration requirements can be very different in all cases. Second, the cost of planting seagrass depends on a series of factors including type of labor depth of planting, experience with planting action, type of equipment, accessibility to planting site, and proximity of available donor plant materials. Third, costs can vary based on the size of job and degree of site constraints especially where small-scale and large-scale restoration projects are performed. Costs should take into account the scale of operation. In addition, some costs may or may not include costs for transportation and other costs (i.e., insurance, payroll, administrative overhead, profit, etc.). As a result of these conditions and the variability of site restoration attempts, caution should be taken in using these estimates to determine future restoration costs.

4.2.3.3 Freshwater Aquatic Beds (Submerged and Floating Vegetation)

No cost data were identified for restoration of freshwater aquatic beds.

4.2.4 Mollusc (Oyster) Reef

Section 2.2.4 identified two technically feasible restoration actions for restoration of injured oyster habitats. These include the following:

- Natural Recovery; and
- Reef Restoration.

The following sections summarize available literature that documents costs for oyster reef restoration activities.

4.2.4.1 Oil Related Literature

As discussed in Chapters 2 and 3, there are no documented cases in the literature where oyster reefs were restored due to oil injury. Contacts with scientific experts and resource management personnel confirmed the absence of reef restoration efforts for oyster reef injury caused by oil discharges. As a result, there are no documented cost data for this restoration application.

4.2.4.2 Non-oil Related Literature

The associated costs of oyster reef restoration activities are documented in several sources which detail reef restoration performed as a result of structural injury to the reef habitat. The following literature sources identify costs related to reef reconstruction: Hofstetter (1981a,b); Berrigan (1988a,b, 1990); Marwitz and Bryan (1990); Bowling (1991a,b); and Soniat et al. (1991). Costs for reef reseeding using seed oysters were obtained by the Maryland Department of Natural Resources (MDNR, 1991).

4.2.4.3 Cost of Restoration Actions

4.2.4.3.1 Natural Recovery

Costs of monitoring programs are discussed in Section 4.4.

4.2.4.3.2 Reef Restoration

Reef restoration includes two techniques: reconstruction of oyster reef substrate using alternative materials, and reestablishment of the habitat or other comparable site with seed oysters. The reported costs for each action are provided below.

4.2.4.3.2.1 Reef Reconstruction

Historical reef restoration projects were performed using materials suitable for reef reconstruction for oyster settlement. The placement of suitable substrate, or clutch, is a potentially successful action for increased oyster colonization if it is performed in areas with adequate bottom types (i.e., conducive for immediate oyster set) (Kennedy, 1991; Webster and Meritt, 1988). In general, oysters settle best on bottom types that are firm, such as those of rock, stone, or shell.

Cost estimates were derived from the literature for several types of materials, demonstrated as feasible actions for oyster reef restoration. These materials include shell (oyster and clam), limestone, gravel, and concrete. The reported costs of restoring injured oyster reef habitats with different materials represent the total costs for obtaining material, transportation (all phases) of material, and distribution onto the seafloor. The costs for reconstruction activities using these materials were derived based on actual restoration projects performed in specific geographical regions. Exhibit 4.8 summarizes costs for reef reconstruction for each material. Data on project costs for reef restoration are presented on a per unit basis, represented as the dollar cost per hectare of habitat restored. Costs range from approximately $3,453 to $13,896 per hectare of habitat restored and were adjusted to reflect mid-1992 dollars.

Costs for reef restoration actions vary due to different restoration requirements and commonly incorporate costs for materials, labor, and transportation requirements. The cost of materials used for reef reconstruction will vary based on the availability of useable substrate in addition to the location of the material supply. Transportation costs are generally factored into reef restoration costs due to the immediate need for material pick-up (at the supply site) and *in situ* placement (using both land and water transportation sources).

As referenced in the literature for past restoration projects, the agency sponsoring the restoration work generally performs the post-restoration monitoring activities. Cost data have historically not been provided for reef monitoring. It is assumed that reef monitoring takes place as part of routine resource management activities. Information from past reef restoration projects suggests that these costs are not generally separated in the computation of total costs for a restoration project. It is common practice for a restoration project to be performed on a contractual basis, where the costs of each activity are included in the total bid price of the restoration contract (i.e., cost of materials, transportation, and labor).

4.2.4.3.2.2 Reseeding of Mollusc Reefs

It is common practice for managers of regional oyster fisheries to cultivate seed oyster grounds for stocking purposes. Seed oysters are small, not-fully-developed oysters that are commonly raised in hatcheries or specially designated oyster beds. The rate of oyster reef restoration may be enhanced by transplanting seed oysters onto the reef site or to an established off-site reef habitat.

In a review of oyster restoration literature that identified several reef reconstruction projects performed in the past, no projects were identified that specifically performed reef restoration by reseeding the oyster bed with seed stock obtained from oyster hatcheries or private seed beds. Cost estimates of this procedure, therefore, were gathered from habitat management personnel at MDNR (MDNR, 1992). The MDNR performs annual seeding activities in the oyster beds located in the Chesapeake Bay and often restores the oyster stock in managed beds using seed material. Through information and data from management officials, unit costs for reseeding were estimated to range from approximately $1,153 to $1,339 per hectare of oyster bed reseeded (see Exhibit 4.8). These costs were derived from data on total fiscal expenditures for seed oysters and the total number of acres planted, adjusted to reflect costs in mid-1992 dollars.

The supply of oyster seed stock used for reseeding public oyster grounds is sometimes provided by privately-owned seed oyster harvesters who contract with habitat management authorities (MDNR, 1992). These suppliers commonly offer seed oysters at discount for state management purposes. Therefore, the prices at which state management agencies receive seed supply may not reflect their true market cost.

Exhibit 4.8 Reported costs for mollusc (oyster) reef restoration ($/ha in mid-1992 dollars).

Restoration Action and Material Used	Reported Cost	Source
Reef Construction		
Shell: Dredged Oyster	$7,543 - $13,896	Maryland Dept. of Natural Resources, 1992
	$3,453	Hofstetter, 1981
	$5,750	Bowling, 1991
Fresh Oyster	$1,860 - $4,323	Maryland Dept. of Natural Resources, 1992
Dredged Clamshell	$5,313	Soniat, et. al., 1991
	$12,377	Berrigan, 1988
	$10,171	Berrigan, 1990
	$3,302	Marwitz and Bryan, 1990
Limestone	$7,249	Soniat, et. al., 1991
Gravel	$6,876	Soniat, et. al., 1991
Concrete	$5,958	Soniat, et. al., 1991
Reef Reseeding		
Seed Oysters	$1,153 - $1,339	Maryland Dept. of Natural Resources, 1992

4.2.5 Coral Reef

As discussed in Section 2.2.5, the available actions for restoration of injured coral reefs include the following:

- Natural Recovery; and

- Reef Restoration using Coral Transplants.

The following sections summarize available literature on restoration costs for each action.

4.2.5.1 Oil Related Literature

The literature on restoration of coral reefs injured by oil does not identify any demonstrated actions other than allowing natural recovery to occur and monitoring. However, the use of coral transplants as a restoration method was a recommended action (Fucik et al., 1984). This method was not demonstrated in an oil discharge restoration effort and no costs for this application were documented.

4.2.5.2 Non-oil Related Literature

Restoration cost information related to coral reef restoration was documented in one report (NOAA, 1991). A recent restoration project was performed on injured corals in the Key Largo Marine Sanctuary due to a ship grounding in 1989. Associated costs of this restoration action were obtained from the National Oceanic and Atmospheric Administration (NOAA), the sponsoring agency of the restoration effort (NOAA, 1991).

4.2.5.3 Costs of Restoration Actions

4.2.5.3.1 Natural Recovery

Costs of monitoring programs are discussed in Section 4.4.

4.2.5.3.2 Reef Restoration using Coral Transplants

The estimated unit costs derived for coral reef restoration were based on the restoration activities and associated costs detailed for the *M/V Elpis* grounding (NOAA, 1991). This event occurred in the Key Largo National Marine Sanctuary in November 1989. For this incident, restoration costs were estimated as part of the damage assessment.

Costs for reef restoration include the cost of activities and resources necessary to complete coral colony transplants. The unit costs estimated for restoration of coral reef habitats was based on the number of square meters of injured reef on which corals were transplanted. This unit measure of reef area is a common measure often used throughout the scientific literature to describe coral growth and cover. Cost estimates of coral reef restoration using coral colony transplants were derived from available data on the *M/V Elpis* restoration project, where several hundred square meters of reef were restored through the use of coral transplants. The cost components for restoration of this nature include the costs for labor (i.e., divers and a material handler) and materials (i.e., boat, air tanks, and supplies). These costs are summarized in Exhibit 4.9. Costs for reef restoration, adjusted to reflect mid-1992 dollars, total $236.83 per square meter of reef restored.

4.2.6 Estuarine and Marine Intertidal

This section presents estimates of costs for the restoration of estuarine and marine habitats using the action described in Section 2.2.6. Cost estimates are derived as the cost of actual restoration efforts reported in the literature, or as "engineered" estimates costing out using the techniques described in the literature. For each habitat, a range of costs is presented. Costs are also presented as unit costs (per square meter of surface area) in mid-1992 dollars. The habitats covered in this section include rocky shores, cobble-gravel beaches, sand beaches, and mud flats, as well as four bottom types.

4.2.6.1 Rocky Shore

Section 2.2.6.1 presents a discussion of the restoration actions that are relevant and feasible for this habitat. This section presents costs estimates for the following actions:

- Natural Recovery;
- Sand Blasting;
- Steam Cleaning;
- Flushing; and
- Bioremediation.

Exhibit 4.9 Reported costs for coral reef restoration ($\$/m^2$ in mid-1992 dollars).

Cost Components		**Restoration Action**
		Coral Colony Transplants
Labor:		
Divers (2):	Base Pay	$67.27
	Dive Pay	16.82
	Overhead/Benefits	36.66
Material Handler:	Base Pay	20.27
	Overhead/Benefits	11.05
Materials/Equipment:		
Diving Boat		80.01
Air Tanks		3.50
Cement		0.80
Plaster		0.45
Total		$236.83

Source: National Oceanic and Atmospheric Administration, 1991.

4.2.6.1.1 Oil Related Literature

Several literature sources were used and a number of experts were contacted in developing the cost estimates for rocky intertidal restoration. Moller et al. (1987) discuss steam cleaning costs. Anderson et al. (1983), Christian (1991), Hogan (1991), and R.S. Means (1990) were used to develop flushing cost estimates. In addition, Dick Lessard of Exxon was contacted for information regarding the use of chemical restoration in flushing efforts. Several literature sources were used in the development of bioremediation cost estimates, including Chianelli et al. (1991), Pritchard and Costa (1991), and Jones and Greenfield (1991). Russ Chianelli and James Bragg of Exxon, Alain Drexler and Paul Benn of Elf-Aquitaine, and Tom Merski of the National Environmental Technology Applications Corporation were also interviewed about bioremediation.

4.2.6.1.2 Non-oil Related Literature

Sand blasting costs were adapted from the Means Construction Cost Guide (R.S. Means Company, 1986). Fertilizing costs from the McMahon Heavy Construction Cost Guide (1990) were used to estimate level of effort in bioremediation.

4.2.6.1.3 Cost of Restoration Actions

4.2.6.1.3.1 Natural Recovery

Costs of monitoring programs are discussed in Section 4.4

4.2.6.1.3.2 Sand Blasting

Cost estimates for sand blasting in rocky intertidal habitats are developed from the costs presented in the Means construction cost guide (R.S. Means Company, 1986). According to this guide, the average cost (in 1992 dollars) of sand blasting using a wet system is \$15.69 per m^2. Adding a 50 percent premium to this figure to reflect the logistics of travelling to and working in possibly remote sites or coastal areas, this unit cost is estimated to be \$23.54 per m^2.

4.2.6.1.3.3 Steam Cleaning

Moller et al. (1987) compare the costs of various steam cleaning techniques. They provide data on actual response and efforts conducted worldwide. Steam cleaning was used to restore the shoreline stained following the discharge of 22,000 barrels of heavy crude oil in the Far East. Moller et al. report the unit cost to steam clean the shoreline to be approximately \$4.82 per m^2 in this case.

4.2.6.1.3.4 Flushing

Unit cost estimates for the *in situ* treatment of rocky intertidal shores were derived assuming that washing of the shoreline is performed using a low- to medium-pressure flushing action since the action is essentially the same in any habitat. The efficiency of rock washing was estimated using data from (Anderson et al., 1983). This account of the late stages of an actual oil discharge response using flushing demonstrated that 20 to 50 m^2 of shoreline were cleaned per hour by each cleanup crew. The midpoint rate of 35 m^2 per hour was assumed as the expected efficiency of cleaning. Following discussions with several oil discharge response cooperatives and discharge response companies, unit costs were derived based on prevailing labor rates and rental rates for the necessary equipment.

A three person cleanup crew was determined as the basic unit of efficiency. Labor costs were estimated using the labor rate of the Corpus Christi Area Oil Spill Control Association (Christian, 1991), Clean Harbors (Hogan, 1991), and the Means Building Construction Cost Data (R.S. Means Company, 1990). An average per person hourly rate of $30.16 was estimated for a total labor cost of $90.47 per hour.

Equipment needs for flushing were determined to include a pressure spray unit plus a vehicle (either a truck or small boat, depending on access to the contaminated habitat). Again using figures from the Corpus Christi Area Oil Spill Control Association (Christian, 1991), Clean Harbors (Hogan, 1991), and the R.S. Means Company (1991), an approximate cost range of $30 to $40 per hour was estimated.

The cost of equipment necessary to recover and absorb dislodged contaminants were estimated using the same sources. The equipment needed for this procedure includes a small portable skimmer unit along with sorbent sweeps or booms. A cost range of $50 to $70 per hour was estimated for the recovery equipment.

The estimated total costs (including equipment and labor) for rocky intertidal shore washing and recovery in current year dollars ranged from $172.31 to $192.77 per hour. Taking the midpoint of this range as the overall estimate, a total of $182.54 per hour was estimated. Assuming the 35 m^2 per hour cleaning rate noted above, the estimated unit cost for the *in situ* treatment of rocky intertidal shore is $5.22 per m^2.

Chemical treatment of the contaminated shoreline was assumed to use a chemical such as Exxon's Corexit 9580. Corexit is sprayed onto the shoreline 15 to 30 minutes prior to the flushing operation and applied at a concentration of 0.5 to one gallon per 9.3 m^2 (i.e., per 100 ft2, Lassard, 1992). Exxon sells Corexit 9580 for approximately $16 per gallon, so at the above concentration, chemical treatment prior to flushing would add $1.30 per m^2. This yields a total for chemical treatment and flushing of $6.52 per m^2.

The following summarizes the estimated unit costs for flushing in rocky intertidal habitats:

Description	Cost per square meter
Flushing	$5.22
Flushing with chemical treatment	$6.52

4.2.6.1.3.5 Bioremediation

Merski (1992) describes the application of the nutrient and microbe combination Alpha BioSea in two field situations. The first was the application of Alpha BioSea to a 12 to 16 hectare surface area of the Gulf of Mexico following the *Mega Borg* tanker discharge and fire. While this was not conducted in the intertidal zone, costs for a one-time application of the agent was approximately $38,000, or about $0.27/m^2 of sea surface area. This same agent was used following the *Apex Barge* discharge in Galveston Bay. Following oiling of nearby marsh, Alpha BioSea was applied to approximately 30 hectares of marsh land at an approximate cost of $39,500. This equates to approximately $0.13/m^2 of surface area. Bioremediation treatment costs in these types of efforts are likely to be much lower than in the intertidal shoreline. It should be noted that these applications of bioremediation did not produce the desired effect and that additional applications may have been necessary. Thus, this cost may represent a lower bound for a one-time application, not a comprehensive bioremediation plan.

In order to estimate costs for the application of an oleophilic nutrient to an oil-contaminated shoreline, the methods described by Pritchard and Costa (1991) and Chianelli et al. (1987) for the *Exxon Valdez* discharge cleanup are used. The basic level of operations assumes a boat is required for access to the shoreline, that tanks are used for holding and heating the nutrient, and that a crew of workers are deployed on the shoreline with backpack sprayers or hoses to apply the fertilizer.

A three person crew was determined as the basic unit of efficiency. Labor costs were estimated using the labor rate of the Corpus Christi Area Oil Spill Control Association (personal communication, 1991), Clean Harbors (Hogan, 1991), and the Means Building Construction Cost Data (R.S. Means Company, 1990). An average per person hourly rate of $30.16 was estimated, for a total labor cost of $90.47 per hour. Equipment needs for flushing were determined to include a backpack sprayer or tanks and hoses, plus a vehicle typically a small boat. Again using figures from the Corpus Christi Area Oil Spill Control Association (1991), Clean Harbors (Hogan, 1991), and the R.S. Means Company (1991), an equipment cost of $51.08 per hour was estimated. A total cost of $141.55 per hour was thus estimated for equipment and labor.

Costs for the oleophilic liquid fertilizer Inipol EAP 22 were obtained from Elf-Aquitaine, the manufacturer of the product (Benn, 1992). The following is a schedule of material costs for 440-pound drums, reflecting discounts for increased volumes:

1-9 drums	\$3.20/lb
10-24 drums	\$3.10/lb
25-79 drums	\$2.90/lb
80+ drums	\$2.65/lb

High demand for this product may necessitate additional production runs of Inipol which may drive up the cost. Bioremediation will likely be used only in light oiling situations, for small discharges, or for "polishing" operations following other response operations. Thus, it is not expected that any one bioremediation restoration effort will have the effect of driving up the material costs of Inipol.

The results from Chianelli et al. (1991) and Pritchard and Costa (1991) indicate that approximately 0.09 gallons of Inipol should be applied per m^2 of surface area. One 440-pound drum of Inipol costs \$1,408, or \$25.60 per gallon (\$1,408/55). The cost for fertilizer is thus \$2.30 per m^2 of shoreline treated.

To estimate the rate of application, figures were taken from the McMahon Heavy Construction Cost Guide (1990) for the rate of fertilizing operations. This is a reasonable surrogate for bioremediation since the basic operations are similar. According to McMahon, it requires five minutes of effort to fertilize 1,000 ft2 of a flower bed, and 30 minutes to fertilize 1,000 ft^2 of trees. These two operations are selected to represent a range of effort required depending on the terrain treated. A flower bed is similar to an easily-accessible, flat shoreline, and trees present barriers to simple spraying operations. These two operations were converted to square meters, resulting in estimated application rates of 0.0538 minutes per m^2 for rapid fertilizer deployment, and 0.3228 minutes per m^2 for slower deployment.

Using these rates, the range of cost for labor and equipment is \$0.13 to \$0.76 per m^2. Adding fertilizer costs increases that the range for total cost are \$2.43 to \$3.06 per m^2.

Material costs for the granular nutrient Customblen were not available at the time of this writing, and thus the costs for the deployment of this nutrient cannot be estimated. The cost for the spreading granular fertilizer will not likely differ greatly from the application of liquid fertilizer.

The estimation of the application of bacterial agents in the intertidal zone will also not differ from the application of nutrients only since the basic operations will likely be similar. When bacterial agents are spread on a shoreline, the operations will resemble the *Exxon Valdez* bioremediation efforts more than the application of BioSea following the *Apex Barge* discharge.

To estimate the cost for the application of bacterial agents, the same methodology used for Inipol cost estimation was utilized. Costs and volume application figures were substituted. Merski (1992) estimates costs for microbial agents to range from \$20 to \$25 per pound. Jones and Greenfield (1991) note that bacterial bioremediation agents cost about \$15 per pound. The midpoint of these figures yields a cost of approximately \$20 per pound. The rate of application of granular fertilizer following the *Exxon Valdez* discharge described by Pritchard and Costa (1991) and Chianelli et al. (1991) averaged about 0.14 pounds per m^2. Material costs are thus \$2.70 per m^2 for bacterial agents. Using the same equipment and labor costs detailed above, the range of total bioremediation costs for the application of bacterial agents is \$2.83 to \$3.46 per m^2.

An intensive effort involving both bacteria and fertilizer over a 194-day period following a discharge of fuel oil at a power plant is described by Jones and Greenfield (1991). Efforts included site alterations to control drainage, application of nutrients, water, and bacteria, and sediment tilling to increase aeration. An area of 4,039 m^2 (44,000 ft2) was treated at a cost of \$44 per metric ton. Jones and Greenfield estimate a typical range of cost for bioremediation to be \$22 to \$44 per metric ton, and the cost of bacteria to be approximately \$33 per kilogram.

In order to estimate this unit cost per unit of surface area, the cost per metric ton figure needs to be converted. To accomplish this, an average weight per volume of twelve was derived from the McMahon Heavy Construction Cost Guide (1990). Clay, earth, mud, sand, and gravel of different degrees of compactness and moisture weigh 1.57 metric tons per m^3. Jones and Greenfield's bioremediation costs are thus evaluated on a volumetric basis, and yield unit costs of \$34.60 per m^3 to \$69.20 per m^3. Furthermore, Jones and Greenfield note that the oil contamination in this discharge penetrated to a depth of 15 to 20 cm. Assuming bioremediation efforts are conducted to the depth of 20 cm, and adjusting the above costs for inflation, yields a range of costs of \$7.19 per m^2 to \$14.39 per m^2. Note that these costs are estimated for an intensive bioremediation effort conducted on land (not the intertidal zone), and one which utilized bacterial agents. At this time, it is unclear whether adding bacterial agents contributes any additional restoration benefit in the intertidal zone since many of the earth's marine waters are rich in such agents (Chianelli, 1992).

The following table summarizes the estimated unit costs for bioremediation:

Description	Cost range per square meter
Spray Alpha BioSea from boat onto open sea	$0.27
Spray Alpha BioSea from boat onto mangroves	$0.13
Add nutrients only	$2.43 to $3.06
Add bacterial agents	$2.83 to $3.46
Intensive terrestrial effort with bacterial agents	$7.19 to $14.39

Among the bioremediation efforts detailed in the above table, the spraying of fertilizer or bacterial agents are among most frequently used for the rocky intertidal habitat. The first two actions in the table involve different types of habitats, while the last effort described involved agitation of sediment with disc harrows to expose soils to air. Tilling sediments is obviously not appropriate in most rocky habitats. Finally, note that the cost to add bacterial agents is not significantly different than the cost of adding nutrients.

4.2.6.2 Cobble-Gravel Beach

This section presents cost estimates relevant to the cobble-gravel intertidal habitat for the following restoration actions:

- Natural Recovery;
- Flushing;
- Sediment Washing;
- Sediment Agitation; and
- Bioremediation.

Cost estimates are derived from descriptions in the literature of the costs of actual field experience and engineered costs derived using techniques described in the literature.

4.2.6.2.1 Oil Related Literature

This section details the literature sources used and experts contacted in developing the cost estimates for cobble-gravel intertidal restoration. Flushing costs were estimated using Anderson et al. (1983), Christian (1991), Hogan (1991), and R.S. Means (1990). In addition, Dick Lessard of Exxon was contacted for information regarding the use of chemical restoration in flushing efforts. Sediment washing estimates were derived using Gumtz (1972), Bocard et al. (1987), Huet et al. (1989), Morris et al. (1982), Jahns et al. (1991), Michel et al. (1991), and Gundlach et al. (1991). Cost estimates for sediment agitation were developed using the American Petroleum Institute (1991), Levine (1987), Miller (1987), the U.S. EPA (1990), and the New Pig Corporation (1992). Interviews with Christian (1991), Hogan (1991), and Levine (1992) were also used. The literature sources were used in the development of bioremediation cost estimates, include Chianelli et al. (1991), Pritchard and Costa (1991), and Jones and Greenfield (1991). Russ Chianelli and James Bragg of Exxon, Alain Drexler and Paul Benn of Elf-Aquitaine, and Tom Merski of the National Environmental Technology Applications Corporation were also contacted for bioremediation information.

4.2.6.2.2 Non-oil Related Literature

Labor costs were estimated using data from the Means Construction Cost Guide (R.S. Means Company, 1990). The McMahon Heavy Construction Cost Guide (1990) was also used to estimate level of effort in bioremediation fertilizing costs.

4.2.6.2.3 Cost of Restoration Actions

4.2.6.2.3.1 Natural Recovery

Costs of monitoring programs are discussed in Section 4.4.

4.2.6.2.3.2 Flushing

Unit cost estimates for the *in situ* treatment of cobble-gravel intertidal shores were derived assuming the same restoration actions as discussed for rocky intertidal shorelines above (see Section 4.2.6.1.3.4.). A range of costs is developed that assumes either the basic flushing operations or a chemical pre-soak with a surface washing agent followed by flushing. These operations are discussed in detail in Section 2.2.6.1.

The following summarizes the estimated unit costs for flushing in cobble-gravel intertidal habitats:

Description	Cost per square meter
Flushing	\$5.22
Flushing with chemical treatment	\$6.52

4.2.6.2.3.3 Sediment Washing

The costs for the selected restoration actions were estimated using the results of Gumtz (1972), Bocard et al. (1987), Huet et al. (1989), and Morris et al. (1982).

Gumtz (1972) describes the costs related to development and field testing of a mobile sediment washing device constructed for the U.S. Environmental Protection Agency. The cost to construct the mobile cleaner in 1992 dollars was \$249,900. Assuming this equipment still exists and is still available for restoration efforts, using such equipment in restoration efforts will not require reinvestment in equipment development. Gumtz (1972) estimates annual operation costs, including unit depreciation, labor, support functions, and maintenance, to be the equivalent of \$48,800 in 1992 dollars. Gumtz estimates a unit cost for operations of about \$2.49 per metric ton of sand. Using the average weight per volume for three types of sand gravel presented in McMahon (1990), an overall average of 1.74 metric tons per m^3 was estimated. The cost for operations is thus \$4.34 per m^3.

In addition to the Gumtz cost estimate, an average sand cleaning cost of approximately \$50 per m^3 of beach material was derived using the technology described in Bocard (1987) and Huet et al. (1989). Using the technology described in Bocard et al. (1987), an average cleaning cost of approximately \$50 per m^3 of beach material was estimated (Huet et al., 1989). This figure was adjusted for inflation and to reflect the overhead and profit charges expected in response and restoration contracts. Overhead and profit was assumed to be 25 percent (R.S. Means Company, 1990). This cleaning cost was then adjusted for inflation, leading to an estimate of \$69.12 per m^3 of contaminated beach material cleaned.

Morris et al. (1982) describe sediment washing in an actual case of an oil discharge restoration project. The results of this effort indicated that it cost approximately \$57.58 per m^3 of beach material. Adjusting for inflation yields an estimate of \$80.36 per m^3.

The midpoint of the two cost estimates above is \$74.74 per m^3. Because of the variable depth to which intertidal habitats may be oiled, it is necessary to estimate costs for cobble and gravel habitats separately from sand habitats.

An overall range of estimates for using the beach washing technology for the *in situ* restoration of cobble and gravel intertidal shorelines was derived by adjusting the Gumtz estimate of \$4.34 per m^3 and the engineered cost of \$74.74 per m^3 to reflect the depth of beach material to be removed. The results Jahns et al. (1991), Michel et al. (1991), and Gundlach et al. (1991) were used in this estimation. Jahns et al. (1991) noted oil penetration of 50 to 100 cm in these environments. Michel et al. (1991) estimated penetration to occur 25 to 50 cm, and Gundlach et al. (1991) noted 40 to 60 cm depth. Taking a rough midpoint of 50 cm, it was assumed that 53 cm of gravel or cobble beach material would need to be removed for cleaning. This depth includes a 3 cm buffer to represent the imprecision of beach removal equipment or human error in removing exactly 50 cm of material. Assuming that cleaning crews dig to 53 cm, estimates for cleaning cobble and gravel intertidal habitats range from \$2.30 to \$39.61 per m^2 of beach surface area.

The range of costs appears to arise from the volume of material processed. Whereas Gumtz estimates operating costs on an annual basis (equivalent to about 11,250 m^3 of sand), Huet et al. base their estimate on the cleaning of just 1,800 m^3 of pebbles. Therefore, fixed costs, such as equipment set-up, will be higher per unit of surface area for small discharges. The range of costs presented below should thus be viewed relative to the size of a discharge event. Small discharges will likely have higher *unit* costs, and vice versa.

The following table summarizes the estimated unit costs for sediment washing in cobble-gravel intertidal habitats:

Description	Cost range per square meter
Mobile sediment washer	\$ 2.30
Engineered cost estimate	\$39.61

4.2.6.2.3.4 Sediment Agitation

Levine notes that the total cost for development and deployment of two Muck Monster boats and two Muck Monster bulldozers fell into the range of \$1.5 to \$2 million (American Petroleum Institute, 1991). Since Levine (1987) describes the area in which the restoration effort was conducted (2,134 linear meters of shoreline was cleaned to a width of about 27.5 meters), a cost range may be estimated per unit of surface area. This area equates to 58,550 m^2, yielding a unit cost range in 1992 dollars of \$26.21 to \$34.95 per m^2.

Since future shoreline agitation efforts will not be faced with the development costs to create a Muck Monster. Future agitation costs are expected to be lower. Levine (1992) stated that a similar effort conducted now could be performed at a reduced cost. Assuming that the expertise is readily available, and that no experimental efforts are undertaken during restoration efforts, the following shoreline agitation costs are estimated for the use of the Muck Monster technology. (Note that this particular technology is patented by Arco Marine, Inc., who must be contacted prior to the use of the Muck Monster.)

This estimate takes into account all items needed for shoreline agitation, and estimates their cost based on the published costs for various items. Based on Levine (1987), Miller (1987), and conversations with Levine (1992), the following equipment was used in the *Arco Anchorage* restoration: sorbent boom, sweeps, two bull dozers or log skidders, two water pumps, a vacuum truck, two skiffs, and approximately 18 personnel.

Costs for equipment were determined using price lists presented for an oil discharge cooperative (Christian, 1991), the Environmental Protection Agency (U.S. EPA, 1990), and a commercial catalog (New Pig, 1992). Whenever possible, the midpoint of a range of multiple sources was used to represent costs of different types of organizations. Labor costs were estimated using the labor rate of the Corpus Christi Area Oil Spill Control Association (Christian, 1991), Clean Harbors (Hogan, 1991), and the Means Building Construction Cost Data (R.S. Means Company, 1990). All cost are in mid-1992 dollars.

The following table presents itemized cost estimates for shoreline agitation using the Muck Monster:

Sorbent Boom	$ 27,888.00
Sweeps	$ 53,922.00
Bull Dozer/Log Skidder (2)	$102,782.40
Pumps (2)	$ 10,965.36
Vacuum Truck	$ 29,400.00
Skiffs (2)	$ 16,128.00
Labor (18)	$312,699.00
Total	$553,784.76

As noted above, the restoration following the *Arco Anchorage* discharge covered a surface area of 58,550 m^2. The expected cost of the efficient use of the Muck Monster technology is thus $9.46 per m^2.

The following table summarizes the estimated unit costs for shoreline agitation:

Description	Cost range per square meter
Efficient use of Muck Monster technology	$9.46
Costs for Muck Monster development and operation	$26.21 to $34.95

4.2.6.2.3.5 Bioremediation

Bioremediation efforts in cobble-gravel intertidal habitats are essentially the same as those described in detail in the rocky intertidal sections of this report (see Sections 2.2.6.1.3.5. and 4.2.6.1.3.5.). This effort provides a range of cost figures for various bioremediation efforts, although as the following table shows, there is not a great deal of variation in the cost of basic operations:

Description	**Cost range per square meter**
Spray Alpha BioSea from boat onto open sea	$0.27
Spray Alpha BioSea from boat onto mangroves	$0.13
Add nutrients only	$2.43 to $3.06
Add bacterial agents	
Intensive terrestrial effort with bacterial agents	$7.19 to $14.39

Realistically, the actions most likely to be used for the cobble-gravel intertidal habitat are the adding of fertilizer or bacterial agents described above. The basic addition of fertilizer to contaminated soil and the adding of bacterial agents do not differ significantly in cost, and their ranges in fact overlap.

4.2.6.3 Sand Beach

Many actions for the restoration of sandy intertidal habitats are similar to those used in cobble-gravel restoration. Differences in methods exist for this habitat, however, due to the increased ecological sensitivity and different penetration of oil into sediments for sand and gravel. Cost estimates are presented below for the following restoration methods:

- Natural Recovery;
- Flushing;
- Sediment Washing;

- Sediment Agitation;
- Bioremediation; and
- Incineration.

4.2.6.3.1 Oil Related Literature

Due to similarities in the habitats, the literature sources used and experts contacted in developing the cost estimates for sand intertidal restoration are the same as those described in Section 4.2.6.2.1. Holoboff and Foster (1987), however, were used rather than Jahns et al. (1991), Michel et al. (1991), and Gundlach et al. (1991) to estimate the depth of oil penetration in sand sediments.

4.2.6.3.2 Non-oil Related Literature

Information obtained through personal communication with Garbaciak (1992), which detailed incineration of contaminated sand sediments, was used in developing incineration cost estimates.

4.2.6.3.3 Cost of Restoration Actions

4.2.6.3.3.1 Natural Recovery

Costs of monitoring programs are discussed in Section 4.4.

4.2.6.3.3.2 Flushing

Unit cost estimates for the *in situ* treatment of sand intertidal shores were derived assuming the same restoration actions as discussed for rocky intertidal shorelines above (see Section 4.2.6.1.3.4.). Christian (1991) indicates the appropriateness of this action for sand shorelines. A range of costs is developed that assumed either the basic flushing operations or a chemical pre-soak with a surface washing agent followed by flushing. These operations are discussed in detail in Section 2.2.6.1.

The following summarizes the estimated unit costs for flushing in sand intertidal habitats:

Description	Cost per square meter
Flushing	$5.22
Flushing with chemical treatment	$6.52

4.2.6.3.3.3 Sediment Washing

The costs for sediment washing were adapted using the same actions assumed for cobble-gravel shorelines (see Section 4.2.6.2.3.3. above). The primary difference between the washing of sediment from cobble-gravel or sand beaches is the difference in the depth to which oil will penetrate in either environment. Holoboff and Foster (1987) report an estimated penetration of 30 to 40 cm in their experimental data. Using their 30 cm figure, it was assumed that at least 33 cm of sand would have to be removed for cleaning. This would allow for a 3 cm buffer for error in the use of any digging or bulldozing type of machinery, which are not precise enough to extract exactly 30 cm of soil. Assuming that cleaning crews will dig to a depth of 33 cm, an overall estimate for cleaning sand intertidal habitats of $24.65 per m^2 of beach surface area was derived. The lower bound of the estimated range of costs is taken from Gumtz (1972).

The following summarizes the estimated unit costs for sediment washing in sand intertidal habitats:

Description	Cost range per square meter
Field experimentation with mobile sediment washer	$ 2.30
Engineered cost estimate	$24.65

4.2.6.3.3.4 Sediment Agitation

The estimated costs for shoreline agitation in sand intertidal habitats are estimated to be the same as those for agitation in cobble-gravel environments (see Section 4.2.6.2.3.4.). Again, the range of possible costs given includes the use of Arco Marine's Muck Monster technology and development and deployment of some other type of sediment agitating technology.

The following table summarizes the estimated unit costs for shoreline agitation:

Description	Cost range per square meter
Efficient use of Muck Monster technology	$9.46
Costs for Muck Monster development and operation	$26.21 to $34.95

4.2.6.3.3.5 Bioremediation

Bioremediation efforts in sand intertidal habitats are essentially the same as those described in detail in the rocky intertidal sections of this report (Sections 2.2.6.1.3.5. and 4.2.6.1.3.5.). This effort provides a range of cost figures for various bioremediation efforts, although as the following table shows that there is not a great deal of variation in the cost of basic operations:

Description	Cost range per square meter
Spray Alpha BioSea from boat onto open sea	$0.27
Spray Alpha BioSea from boat onto mangroves	$0.13
Add nutrients only	$2.43 to $3.06
Add bacterial agents	$2.83 to $3.46
Intensive terrestrial effort with bacterial agents	$7.19 to $14.39

As in the case of the other intertidal habitats, the actions most likely to be used for the sand intertidal habitat include the addition of fertilizer to contaminated soil or the addition of bacterial agents. These two actions, however, do not differ significantly in cost.

4.2.6.3.3.6 Incineration

Unit costs for the incineration of sediments in sand intertidal habitats were estimated using project cost data provided by the U.S. Army Corps of Engineers (Garbaciak, 1992). Costs were provided for a number of incineration related activities. The different activities are used to estimate a range of incineration unit costs. The following table shows the costs per volume of material for a number of activities:

Description	Cost per cubic meter
Incinerate material	261.58
Remove large debris	$2.62
Dewater material	$3.92
Rehandle material into incinerator	2.62
Treat removed water	$5.23
Solidify ash	$58.85
Rehandle material into disposal site	$1.31
Total	$336.13

The cost, therefore, of an intensive incineration effort, including a number of incineration activities, is $336.12 per m^3. To develop a lower end of the range of incineration costs, the cost of incineration alone, $261.58 per m^3, was used.

In order to convert these costs to costs per surface area, the results of Holoboff and Foster (1987) described in detail for sediment washing were used. As indicated above, approximately 33 cm of sand sediment is likely to be removed for restoration. Assuming oil penetrates to a depth that requires this much material be removed, the following range of unit costs per surface area for incineration of sand sediments is estimated:

Description	Cost range per square meter
Incineration of sand alone	$ 86.32
Intensive incineration effort	$110.92

4.2.6.4 Mud Flat

This section presents a discussion of the costs of restoration actions appropriate to mudflats. Specifically, cost estimates are presented for the following:

- Natural Recovery;
- Sediment Removal and Replacement; and
- Bioremediation.

4.2.6.4.1 Natural Recovery

Costs of monitoring programs are discussed in Section 4.4.

4.2.6.4.2 Sediment Removal/Replacement

A restoration method was assumed which involves removing contaminated soil, loading and transporting it for disposal, and obtaining and deploying replacement soil in its place. Cost estimates for removing contaminated soil, and purchasing and spreading new soil were obtained from *Means Building Construction Cost Data 1991* (R.S. Means Company, 1990). Cost data for loading, trucking, and disposing contaminated soil were gathered to represent a range of conditions and scenarios. Calculated costs were also converted to mid-1992 price levels.

Stripping, new soil, and spreading costs were calculated per m^3 of soil. A 100 percent premium was added to the Means construction cost figures to represent the additional effort required to deal with wet material expected in the intertidal zone. The costs estimated were as follows: stripping and piling on-site for loading, \$6.34 per m^3; replacement soil (screened loam), \$29.42 per m^3; and spreading new material from pile to rough finish grade, \$9.61 per m^3. This results in a total cost of \$45.37 per m^3 of contaminated soil for stripping, new soil, and replacement.

Exhibit 4.10 presents the disposal costs estimated by several sources. The organizations contacted are located throughout the United States and consist of one oil discharge response cooperative, two oil discharge response and/or remediation companies, and two hazardous waste management companies. Since the contaminant is assumed to be non-hazardous, the soil need not be treated or stabilized prior to disposal in an upland landfill. The cost estimated by Clean Harbors was per 55 gallon drum disposed; volume discounts are expected when disposal occurs with larger containers. Since the clean Harbors estimate is considerably higher than the others in Exhibit 4.10 it was treated as an outlier and omitted from the calculation of an overall unit cost for disposal. The high range of the remaining estimates were used to calculate the overall average disposal cost of \$166.82 per m^3 of soil.

Harper and Humphrey (1985) note that oil penetration in mud flats occurs to a depth range of 2 to 4 cm. Unit costs are calculated per square meter of surface area assuming that soil is contaminated to a depth of 2 cm. As in other sections, a 3 cm buffer is added to the assumed penetration depth to reflect the imprecision of digging to an exact depth. Overall, 5 cm of soil are assumed removed and disposed. As a result, the overall costs are assumed to be \$2.27 per m^2 of mud flat surface area for restoration and \$8.35 per m^2 for disposal.

The following table summarizes the estimated unit costs for removal, replacement, and disposal of contaminated mud flat intertidal sediments:

Description	**Cost range per square meter**
Removal and replacement	\$2.27
Disposal	\$8.35

Exhibit 4.10 Reported monitoring costs for coral reef restoration using coral transplants ($/m^2 in mid-1992 dollars).

Cost Component		**Duration of Monitoring**				
		Year 1	**Year 2**	**Years 3-5**	**Years 6-10**	**Total Years 1-10**
Labor						
Field:	Principal Investigator	$2.34	$1.14	$0.68	$0.45	$5.06
	Biologists	8.22	1.81	1.08	0.36	11.47
Analysis:	Principal Investigator	18.70	4.52	2.71	1.81	27.74
	Biologists	30.00	7.25	4.36	1.45	43.06
Materials						
Field:	Boat	4.87	2.35	1.41	0.94	9.57
	Supplies	0.79	0.19	0.19	0.19	1.37
Analysis:	Supplies	0.39	0.32	0.32	0.32	1.34
Total Labor and Materials		65.31	17.59	10.75	5.52	99.17
Overhead (100%)		65.31	17.59	10.75	5.52	99.17
Total Monitoring Costs		$130.62	$35.18	$21.50	$11.04	$198.34

Source: National Oceanic and Atmospheric Administration, 1991.

4.2.6.4.3 Bioremediation

Bioremediation in mud flat intertidal habitats is estimated to be the same as estimated for other intertidal habitats. The following table shows the range in the cost of basic bioremediation operations:

Description	Cost range per square meter
Spray Alpha BioSea from boat onto open sea	$0.27
Spray Alpha BioSea from boat onto mangroves	$0.13
Add nutrients only	$2.43 to $3.06
Add bacterial agents	$2.83 to $3.46
Intensive terrestrial effort with bacterial agents	$7.19 to $14.39

As in the case of the other intertidal habitats, the actions most likely to be used for the mud flat intertidal habitat include the addition of fertilizer or bacterial agents to contaminated soil.

4.2.7 Estuarine and Marine Subtidal

4.2.7.1 Subtidal Rock Bottom

There is only one technical feasibility restoration action applicable to subtidal estuarine and marine rock bottom habitats: natural recovery. The costs of monitoring programs are discussed in Section 4.4.

4.2.7.2 Subtidal Cobble-Gravel, Sand, and Silt-Mud Bottom

Section 2.2.7.2 discusses the technical feasibility of restoration actions for subtidal estuarine and marine cobble-gravel, sand, and silt-mud bottom habitats including:

- Natural Recovery;
- Dredging/Sediment Removal; and
- Sediment Capping.

The following sections identify available information on the costs of these actions and summarize reported cost estimates.

4.2.7.2.1 Oil Related Literature

There are no costs reported for oil related restoration of bottom sediments by material removal in cobble-gravel, sand, and silt-mud habitats. Representative cost sources for sediment removal due to other forms of contamination are identified in Section 4.2.7.2.2.

4.2.7.2.2 Non-oil Related Literature

Sediment removal and disposal costs are documented in several literature sources to reflect activities performed in various geographic regions of the United States. Also, recent data were gathered on the costs of actual dredging and disposal activities performed by the USACOE. Phillips and Malek (1987) identify costs related to alternative dredging methods for use in the Puget Sound, Washington area. These costs reflect costs of material removal only, yet present a representative average of equipment costs for the northwestern region of the U.S. Similar costs for the Puget Sound region are identified Cullinane et al. (1990). Eastern Research Group (ERG) (1991) documents a range of cost information for dredging and disposal activities for the management of contaminated sediments. These cost data are provided for sediment removal activities alone, as well as for sediment removal and disposal for three types of disposal methods: open water, near-shore confined, and upland disposal.

Marcus (1992) summarizes costs for contaminated material dredging and disposal for near-shore disposal. Cost data were also provided by the USACOE for maintenance and new work dredging operations performed in 1990 and 1991 in several USACOE districts (USACOE, 1992). The operation costs were categorized based on different types of dredge equipment used and the disposal method selected (i.e., open water, near-shore confined, upland disposal). These data reflect the unit costs of dredging and disposal activities routinely performed by the USACOE and are considered representative data for the majority of dredging projects conducted in various regions of the United States.

4.2.7.2.3 Cost of Restoration Actions

Costs of subtidal cobble-gravel, sand, and silt-mud bottom restoration activities are discussed in the following subsections.

4.2.7.2.3.1 Natural Recovery

Costs of monitoring programs are discussed in Section 4.4.

4.2.7.2.3.2 Dredging/Sediment Removal

The costs of material removal using dredging equipment for cobble-gravel, sand, and silt-mud habitats typically include three main components: the type of dredge equipment used, transport mode, and associated disposal methods. Actual costs of dredging operations were provided by several sources (Phillips and Malek, 1987; Cullinane et al., 1990; ERG, 1991; Marcus, 1991; and USACOE,1992). Based on a review of material removal costs identified in the literature, costs are presented for just material removal activities (i.e., dredging). Costs are also provided which combine dredging, transport, and disposal activities. Each category of costs is presented in Exhibit 4.11.

Material removal costs available which provide costs only for dredging range from approximately $1.38 per cubic meter to $1.54 per cubic meter (Phillips and Malek, 1987; Cullinane et al., 1990). These costs were adjusted to reflect current dollars. This range of costs reflects differences in the type of equipment used, site specific factors, and costs of operations in a given geographic region.

Exhibit 4.11 also identifies a range of costs associated with sediment removal and the associated transport and disposal of the dredged material. These cost components are not broken out for each activity, but shown as a combined cost. Cost information identified in the literature is often specific to the job characteristics in a given region of the United States and therefore costs are not typically documented for each cost component. Costs will vary based on the sediment management strategy selected to appropriately deal with different levels of contaminated sediment, as identified by the range of dredging and disposal costs presented in Exhibit 4.11. The cost ranges presented for each disposal method represent typical costs of performing the specific method, and may vary based on factors such as the level of contamination, type of equipment selected, geographic region as well as the availability of and distance to disposal locations. To develop a reasonably accurate estimate of dredging and disposal costs, one must identify cost components region by region, if not project area by project area. According to ERG (1991), costs can vary significantly even between adjacent areas because of the factors listed above as well as differences in mobilization and demobilization costs. In addition, monitoring, enforcement, and regulatory costs will add to these disposal costs. These cost components are typically not included in documented cost information.

In cases where the costs of transport are not included with the costs of dredging (in order to move dredged sediment to offshore or upland disposal sites), transportation costs may accrue significantly depending on the size of the project. Two literature sources identified cost estimates for two transport modes: truck and barge hauling (Phillips and Malek, 1989; Cullinane et al., 1990).

Exhibit 4.11 Reported costs for subtidal estuarine and marine cobble-gravel, sand, and silt-mud bottom sediment removal and disposal (\$/m^3 in mid-1992 dollars).

Sediment Removal

Source	Costs	Other Data Reported
Phillips and Malek (1987); Cullinane, et al., (1990) Hydraulic Dredging Mechanical Dredging Hopper Dredging	 $1.38 $1.48 $1.28	 Northwestern U.S. Northwestern U.S. Northwestern U.S.
ERG (1991)	$1.54	Average cost U.S.

Sediment Removal and Disposal

Disposal Method	Source	Costs	Other Data Reported
Open Water	ERG (1991) USACE (1992)	$4.25 $0.32 - $10.17	Northeastern U.S. All U.S. Regions
Near-Shore Confined	ERG (1991) Marcus (1991) USACE (1992)	$4.75 - $11.41 $0.30 - $8.97 $0.22 - $20.20	Northeastern U.S. Great Lakes Regions All U.S. Regions
Upland	ERG (1991) USACE (1992)	$4.75 - $11.21 $0.36 - $11.58	Northeastern U.S. All U.S. Regions

Each source reported similar costs, as outlined below:

Source	Cost	Dredged Material Transportation Costs ($/m^3/mile)
Phillips and Malek (1987)	$0.25	Truck transport
Cullinane et al. (1990)	$0.25 -$0.30	Barge transport

4.2.7.2.3.3 Sediment Capping

The costs of capping sediments reflect the costs of obtaining clean dredged material or some other form of loam, sand, or fill which is dredged locally (or taken from a maintenance dredging operation), transported to the disposal, and placed on the contaminated sediment. The capping material is assumed to be dredged at a similar unit cost. Typically a ratio of four parts of capping material to one part contaminated dredge material is considered an appropriate amount of material needed for contaminant isolation (Cullinane et al., 1990; USACOE, 1989; Averett and Palermo, 1989). Available costs of capping material were documented in the literature (Phillips and Malek, 1987; Cullinane et al., 1990; and ERG, 1991). These sources identify costs for capping material to range from about $1.22 per cubic meter to $4.25 per cubic meter. The following table provides a breakout of these cost estimates

Sediment Capping Costs ($/m^3)

Source	Cost	Other Data Reported
Phillips and Malek (1987)	$1.29	Northwestern U.S
Cullinane et al., (1990)	$1.29	Northwestern U.S
ERG (1991)	$4.25	Northeastern U.S

4.2.8 Riverine and Lacustrine Shorelines

The following discusses the costs of the restoration actions considered for riverine and lacustrine (lake) shoreline habitats.

4.2.8.1 Rock Shore

- Natural Recovery;
- Sandblasting;
- Steam Cleaning;

- Flushing; and

- Bioremediation.

4.2.8.1.1 Oil Related Literature

The oil related literature used to develop cost estimates for restoration actions for riverine and lacustrine rocky shore environments is the same as that presented in Section 4.2.6.1.

4.2.8.1.2 Non-oil related Literature

The non-oil literature used to develop cost estimates for restoration actions for riverine and lacustrine rocky shore environments is the same as that presented in Section 4.2.6.1.

4.2.8.1.3 Cost of Restoration Actions

4.2.8.1.3.1 Natural Recovery

Costs of monitoring programs are discussed in Section 4.4.

4.2.8.1.3.2 Sandblasting

Cost estimates for sand blasting in riverine and lacustrine rocky shore habitats are developed in Section 4.2.6.1.3.2. A cost range of \$15.69 to \$23.54 per m^2 was estimated for sand blasting rocky shores.

4.2.8.1.3.3 Steam Cleaning

Using Moller et al. (1987), Section 4.2.6.1.3.3. estimated the unit cost to steam clean rocky shoreline at approximately \$4.82 per m^2. This cost would apply to riverine and lacustrine environments as well.

4.2.8.1.3.4 Flushing

The cost estimates derived in Section 4.2.6.1.3.4. for rocky intertidal habitats also applies to riverine and lacustrine rocky shore environments. The following summarizes the estimated unit costs for flushing in rocky shore habitats:

Description	Cost per square meter
Flushing	$5.22
Flushing with chemical treatment	$6.52

4.2.8.1.3.5 Bioremediation

The following table summarizes the unit costs estimated in Section 4.2.6.1.3.5. for bioremediation. These costs apply to riverine and lacustrine environments:

Description	Cost Range per square meter
Spray Alpha Bio-Sea from boat onto open sea	$0.27
Spray Alpha Bio-Sea from boat onto mangroves	$0.13
Add nutrients only	$2.43 to $3.06
Add bacterial agents	$2.83 to $3.46
Intensive terrestrial effort with bacterial agents	$7.19 to $14.39

4.2.8.2 Cobble-Gravel Shore

The costs derived for intertidal cobble-gravel shorelines apply to riverine and lacustrine environments as well. The costs derived for the following actions are summarized below.

- Natural Recovery;
- Flushing;
- Sediment Washing;
- Sediment Agitation; and
- Bioremediation.

4.2.8.2.1 Oil Related Literature

See Section 4.2.8.2. for the oil related literature used to estimate cobble-gravel shore restoration.

4.2.8.2.2 Non-oil Related Literature

See Section 4.2.8.2. for the non-oil literature used to estimate cobble-gravel shore restoration.

4.2.8.2.3 Cost of Restoration Actions

4.2.8.2.3.1 Natural Recovery

Section 4.4 provides a description of the costs of monitoring programs.

4.2.8.2.3.2 Flushing

Section 4.2.6.1.3.4. provides detailed derivations of unit costs for flushing in cobble-gravel shore habitats. The following summarizes the estimated unit costs:

Description	**Cost per square meter**
Flushing	$5.22
Flushing with chemical treatment	$6.52

4.2.8.2.3.3 Sediment Washing

The following table summarizes the estimated unit costs derived in Section 4.2.6.2.3.3. for sediment washing in cobble-gravel shore habitats:

Description	**Cost per square meter**
Mobile sediment washer	$2.30
Engineered Cost Estimate	$39.61

4.2.8.2.3.4 Sediment Agitation

The following table summarizes the estimated unit costs for sediment agitation. See Section 4.2.6.2.3.4. for a full derivation of these costs.

Description	Cost Range per square meter
Efficient use of Muck Monster technology	$9.46
Costs for Muck Monster development and operation	$26.21 to $34.95

4.2.8.2.3.5 Bioremediation

The following range of cost figures for various bioremediation efforts was developed in Section 4.2.6.1.3.5:

Description	Cost Range per square meter
Spray Alpha Bio-Sea from boat onto open sea	$0.27
Spray Alpha Bio-Sea from boat onto mangroves	$0.13
Add nutrients only	$2.43 to $3.06
Add bacterial agents	$2.83 to $3.46
Intensive terrestrial effort with bacterial agents	$7.19 to $14.39

Practically, the actions most likely used for the cobble-gravel shore habitat include the use of bacterial agents or intensive terrestrial oil removal efforts with bacterial agents described above. The basic addition of fertilizer to contaminated soil and adding of bacterial agents do not differ significantly in cost and their ranges in fact overlap.

4.2.8.3 Sand Shore

- Natural Recovery;
- Flushing;
- Sediment Washing;
- Sediment Agitation;
- Bioremediation; and

- Incineration.

4.2.8.3.1 Oil Related Literature

The oil related literature used to develop cost estimates for restoration in riverine and lacustrine sand shore environments is the same as that used for sand intertidal habitats (see Section 4.2.6.3.).

4.2.8.3.2 Non-oil Related Literature

See Section 4.2.6.3. for a discussion of the non-oil literature used to develop restoration cost estimates.

4.2.8.3.3 Cost of Restoration Actions

The cost of restoration activities in riverine and lacustrine shorelines is the same as the cost for intertidal sand beach restoration.

4.2.8.3.3.1 Natural Recovery

Section 4.4. provides a description of the costs of monitoring programs.

4.2.8.3.3.2 Flushing

The following summarizes the estimated unit costs for flushing in sand shore habitats. These costs are detailed in Section 4.2.6.1.3.4:

Description	Cost per square meter
Flushing	$5.22
Flushing with chemical treatment	$6.52

4.2.8.3.3.3 Sediment Washing

The following table summarizes the estimated unit costs for sediment washing in sand shore habitats. These costs are described in detail in Section 4.2.6.2.3.3.

Description	Cost per square meter
Field experimentation with mobile sediment washer	$ 2.30
Engineered cost estimate	$24.65

4.2.8.3.3.4 Sediment Agitation

The following table summarizes the estimated unit costs for shoreline agitation that were derived in detail in Section 4.2.6.2.3.4.:

Description	Cost Range per square meter
Efficient use of Muck Monster technology	$9.46
Costs for Muck Monster development and operation	$26.21 to $34.95

4.2.8.3.3.5 Bioremediation

The following range of cost figures for various bioremediation efforts was developed in Section 4.2.6.1.3.5.:

Description	Cost Range per square meter
Spray Alpha Bio-Sea from boat onto open sea	$0.27
Spray Alpha Bio-Sea from boat onto mangroves	$0.13
Add nutrients only	$2.43 to $3.06
Add bacterial agents	$2.83 to $3.46
Intensive terrestrial effort with bacterial agents	$7.19 to $14.39

As in the case of the other freshwater shorelines, the actions most likely used for the sand shore habitat include the addition of fertilizer to contaminated soil or adding of bacterial agents. These two actions, however, do not differ significantly in cost.

4.2.8.3.3.6 Incineration

Unit costs for the incineration of sediments in sand shore habitats were estimated in Section 4.2.6.3.3.6. The following table shows a range of unit costs for incineration of sand shore sediments:

Description	Cost Range per square meter
Incineration of sand alone	$86.32
Intensive incineration effort	$110.92

4.2.8.4 Silt-Mud Shore

The actions costed for this habitat were as follows:

- Natural Recovery;
- Sediment Removal/Replacement; and
- Bioremediation.

4.2.8.4.1 Oil Related Literature

See Section 4.2.6.4. for information on the oil related literature used to derive cost estimates for mud flat restoration. In addition to the sources used for mud flat restoration, the American Petroleum Institute (1991) provided an engineered cost estimate for sediment removal and replacement.

4.2.8.4.2 Non-oil Related Literature

See Section 4.2.6.4. for the non-oil literature used in the development of restoration cost estimates.

4.2.8.4.3 Cost of Restoration Actions

In general, the costs estimated for mud flat intertidal habitats also applies to silt-mud riverine and lacustrine shorelines. An additional estimate is provided for sediment removal and replacement, however, for the silt-mud riverine habitat.

4.2.8.4.3.1 Natural Recovery

Section 4.4 provides a description of the costs of monitoring programs.

4.2.8.4.3.2 Sediment Removal/Replacement

In addition to the costs derived in Section 4.2.6.4.3.2., the American Petroleum Institute (1991) presents cost estimates for a discharge scenario in which contaminated streambank sediments are removed and replaced. In order to remove and replace 100 cubic yards of soil, the API estimates 48 hours of labor (at $35 per hour), $2,000 for equipment, and 60 percent of labor and equipment for the disposal or treatment of soil, procurement of replacement soil, and contingency. These cost items total $7,701 for 100 square meters of soil, or $77.01 per m^2. Digging to the five centimeter depth assumed in Section 4.2.6.4.3.2, this equates to a unit cost of $3.85 per m^2 of silt-mud, or $3.94 per m^2 in 1992 dollars. The following table summarizes the estimated unit costs for removal, replacement, and disposal of contaminated silt or mud shore sediments. This table includes the costs estimated in Section 4.2.6.4.3.2 for removal, replacement, and disposal of mud flat sediments.

Description	**Cost per square meter**
Streambank restoration (removal, replacement, and disposal)	$3.94
Removal and replacement	$2.27
Disposal	$8.35

4.2.8.4.3.3 Bioremediation

Bioremediation in silt or mud habitats is estimated to be the same as estimated for other habitats. The following table summarizes the range in the cost of basic bioremediation operations:

Description	**Cost Range per square meter**
Spray Alpha Bio-Sea from boat onto open sea	$0.27
Spray Alpha Bio-Sea from boat onto mangroves	$0.13
Add nutrients only	$2.43 to $3.06
Add bacterial agents	$2.83 to $3.46
Intensive terrestrial effort with bacterial agents	$7.19 to $14.39

As in the case of the other habitats, the actions most likely to be used for the mud flat habitat include the addition of fertilizer to contaminated soil or adding of bacterial agents. See Section 4.2.6.1.3.4. for the full derivation of this range of costs.

4.2.9 Riverine Bottom

4.2.9.1 Rock Bottom

There is only one technically feasible restoration action applicable to riverine rock bottom habitats: natural recovery. Section 4.4 provides a description of the costs of monitoring programs.

4.2.9.2 Cobble-Gravel, Sand, and Silt-Mud Bottom

Section 2.2.9.2. discusses the technical feasibility of restoration actions for riverine cobble-gravel, sand, and silt-mud bottom habitats. These actions include:

- Natural Recovery;
- Dredging/Sediment Removal; and
- Streambed Agitation.

The following sections identify available information on the costs of these actions and summarize reported cost estimates.

4.2.9.2.1 Oil Related Literature

The only documented case of costs for oil related restoration performed in riverine habitats is provided as a case study on restoration in high-energy river and stream habitats (API, 1991). This report estimates costs related to a fuel discharge restoration project performed in Wolf Lodge Creek, Idaho, as documented by Graves (1985). Sediment agitation was performed as the primary restoration action. Costs of performing this action were derived from assumptions about the level of effort required for each activity and cost of equipment and supplies (API, 1991).

4.2.9.2.2 Non-oil Related Literature

No literature is available that documents actual costs of non-oil related restoration performed in riverine habitats. Refer to Section 4.2.7.2.2 for a review of literature that identifies sediment removal costs. The cost information identified for estuarine and marine subtidal bottom habitats is applicable to similar activities performed in riverine habitats.

4.2.9.2.3 Cost of Restoration Actions

Costs of monitoring programs are discussed in Section 4.4.

4.2.9.2.3.1 Natural Recovery

There are no reported costs for restoration actions related to natural recovery.

4.2.9.2.3.2 Dredging/Sediment Removal

Costs of this restoration option are discussed in Section 4.2.7.2.3.2.

4.2.9.2.3.3 Streambed Agitation

The actual costs of streambed agitation, as performed in the Wolf Lodge Creek discharge (Graves, 1985) are not reported by any documented source. However, the costs of performing the sediment agitation action as an option to restore oiled streambeds were estimated based on typical manpower, equipment, and materials requirements. These costs were derived, as reported in API (1991), based on an estimate of the number of hours required to operate equipment as well as costs of using the equipment and other materials. To reflect restoration costs on an areal basis, the derived estimates were converted to unit costs and adjusted to current dollars, as shown below:

Sediment Agitation

Cost Components	Unit Cost ($/m^2)
Labor	$0.02
Equipment	$0.01
Total	$0.03

4.2.10 Lacustrine Bottom

4.2.10.1 Rock Bottom

Section 2.2.10.1. discusses the technical feasibility of one restoration option applicable to lacustrine rock bottom habitats: natural recovery. There are no documented costs in the literature related to this action for lacustrine rock bottom habitats.

4.2.10.2 Cobble-Gravel, Sand, and Silt-Mud Bottom

Section 2.2.10.2. discusses the technical feasibility of restoration actions for lacustrine cobble-gravel, sand, and silt-mud bottom habitats. These actions include:

- Natural Recovery;
- Dredging/Sediment Removal; and
- Sediment Capping.

The following sections identify available information on the costs of these actions and summarize reported cost estimates.

4.2.10.2.1 Oil Related Literature

For subtidal lake restoration, there are no documented costs associated with restoration actions performed due to oil contamination.

4.2.10.2.2 Non-oil Related Literature

Actual cost information related to lake restoration activities is documented in a handful of sources that identify sediment removal as a common lacustrine restoration action. Costs for other restoration actions specific to lake restoration were not found in the literature (e.g., *in situ* sediment capping). Sediment removal costs for dredging activities performed in lake habitats are identified by Peterson (1978, 1982), Cooke (1983), EPA (1988), and Averett et al. (1990). Although there is a significant span of time covered by these documented cases, the cost ranges identified, after adjustment to current dollars, are reasonable estimates relative to site-specific factors.

4.2.10.2.3 Cost of Restoration Actions

Costs of subtidal riverine bottom restoration actions are discussed in the following subsections.

4.2.10.2.3.1 Natural Recovery

Costs of monitoring programs are discussed in Section 4.4.

4.2.10.2.3.2 Dredging/Sediment Removal

Actual costs of sediment removal performed in lakes are reported by Peterson (1978, 1982), Cooke (1983), EPA (1988), and Averett et al. (1990). As discussed in Section 4.2.7.2.3.2, the costs of dredging sediment are affected by several factors. These can include the rate of dredging, quantity of material removed, availability of equipment, operational constraints, and other site specific factors. Exhibit 4.12 provides a summary of costs for lake sediment removal as documented by the above mentioned literature sources. Peterson (1978, 1982) summarizes costs for several lake restoration projects and points out the difficulty in costing out dredging projects on a comparative basis. He also describes why cost figures for freshwater lake dredging projects are less common than are for USACOE navigation projects, citing that until recently there were no federal funds available to conduct or monitor projects. The cost range reported for various lake dredging projects differ due to site specific factors, equipment used, and geographical constraints. Based on available cost data for different regions where lake sediment removal was conducted, it appears that restoration of lakes in the Northeast is much more costly that for other parts of the country. Peterson (1982) also states that removal of contaminated material may increase the costs by three to five times.

Cooke (1983) provides cost estimates for lake sediment removal which range from a few dollars a cubic meter to over $30.00 for removal and handling of contaminated sediment. EPA (1988) provides dredging cost estimates for use of hydraulic equipment as well as presents a generic cost range applicable to various sediment removal equipment types. More recent costs of dredging in the Great Lakes are provided by Averett et al. (1990). The costs presented here are within the cost ranges identified in the other sources.

4.2.10.2.3.3 Sediment Capping

Costs related to sediment containment with use of capping material are discussed in Section 4.2.7.2.3.3. There are no reported costs of this restoration option for lacustrine habitats; however, the costs reported for use of this action in estuarine and marine environments are generally applicable to lake systems.

4.3 Biological Natural Resource Restoration

Costs of restoration actions relating directly to fish and wildlife are discussed in the following sections. Each of the following five subsections: summarizes the oil discharge related and non-oil discharge related fish and wildlife restoration cost literature; provides the cost estimates of restoration actions; and discusses any assumptions or considerations related to the cost estimates of each option for shellfish (Section 4.3.1), fish (Section 4.3.2), reptiles (Section 4.3.3), birds (Section 4.3.4), and mammals (Section 4.3.5).

Exhibit 4.12 Reported costs for subtidal lacustrine restoration ($\$/m^3$ in mid-1992 dollars).

Sediment Removal		
Source	**Reported Costs**	**Other Reported Data**
Peterson (1979)[3] Hydraulic Dredging Bulldozer Dredging	 $0.53 - $6.20 $1.75 - $30.78	Average by Region: Great Lakes $ 2.63 Northwest $ 4.63 Central States $ 4.88 Northeast $11.04
Peterson (1982)[1]	$1.02 - $5.24	Central States Region
Cooke (1983)[1]	$0.30 - $19.00	Contaminated Soil >$34.00
EPA (1988)[1] Hydraulic Dredging General Dredging (Type not specified)	 $2.20 - $3.08 $0.42 - $24.79	 Cost range for 64 projects
Averett, et.al (1990)[4] Hydraulic Dredging Mechanical Dredging Hopper Dredging	 $5.66 - $11.34 $9.73 - $10.60 $5.01 - $7.57	 Contaminated Sediment Removal in Great Lakes Region

3 Reported costs do not include transport, disposal or monitoring costs.

4 Reported costs include transport and monitoring costs.

Natural recovery, or no action, allows injured environments to recover through natural processes. This action is typically used when no restoration alternatives exist or the alternatives would cause more injury than improvement. Natural recovery does require periodic monitoring of the area to ensure that adequate progress and recovery are occurring as expected (see Chapter 3). Restocking expedites the recovery process by introducing, or stocking, species the same as or comparable to those injured.

4.3.1 Shellfish

Shellfish resource restoration literature only provides cost estimates for mollusc reef restoration. A complete discussion of the economic costs related to this restoration is located in Section 4.2.4 (Mollusc Reefs). The following restoration actions are considered in Section 4.2.4:

- Natural Recovery;
- Reef Reconstruction; and
- Seeding of Beds.

Hatchery and seeding programs exist for other types of shellfish; however, these are currently only conducted in laboratory situations and were not established on a commercial basis (Exxon Valdez Oil Spill Trustees, 1992a; Lewis, 1993).

4.3.2 Fish

There exist five technically feasible actions for restoring injured fish habitats and populations. These actions include:

- Natural Recovery;
- Restocking/Replacement;
- Fishery Habitat Restoration and Enhancement;
- Modification of Fishery Management Practices; and
- Habitat Protection and Acquisition.

4.3.2.1 Oil Related Literature

After an extensive search of oil related restoration literature, no sources were located that discussed the costs of restoring fish populations to baseline levels.

4.3.2.2 Non-oil Related Literature

The most recent and comprehensive source of economic values of fish populations is a handbook published by the American Fisheries Society (Riely, Southwick, and Reilly, 1990). Part I of the handbook provides several valuation techniques for evaluating the economic damages resulting from a fish-kill event. The handbook includes replacement costs on a national and regional level, when available, for more than 100 marine and freshwater species, calculated based on a survey of the nation's public and private fish hatcheries.

In 1978, Nelson, Horak, and Olson of Enviro Control, Inc. prepared a handbook sponsored by the U.S. Department of the Interior that summarizes almost 300 fish and wildlife habitat and population improvement techniques. The actions discussed include enhancement techniques proven effective during previous dam and reservoir projects or determined potentially effective by experts in the field. A brief summary of each action provides relative costs among other information, such as engineering features, hydrological effects, biological effects, and related references. The fish and wildlife habitat improvement techniques are divided into several categories: reservoir flood basins; reservoir conservation pools; dam discharge systems; streamflows, riffles, and pools; streamside protection; and general practices. The fish and wildlife population improvement techniques are divided into the following categories: fish propagation; fish passage; fish stocking and control; wildlife propagation and control; and wildlife protection at canals.

Bell et al. (1989) evaluate the biological, physical, and economic effectiveness of eight manufactured artificial reef structures. These structures were tested at sites off the coast of South Carolina as part of the state's Marine Artificial Reef Program. Although the evaluation is ongoing to assess long-term effects, observation within the first three years of the study led to several preliminary conclusions and recommendations. Bell et al. describe the background of South Carolina's Marine Artificial Reef Program, methodology used for this study, specifications of the eight manufactured reef structures tested, economic cost of each reef structure type, and the preliminary results and conclusions of the study.

Prince and Maughan (1978) present and discuss several biological and economic issues relevant to the development of freshwater artificial reefs. The biological issues addressed include fish abundance, fish colonization, fish harvest rates, and fish production in freshwater environments in relation to the existence of artificial reefs. The discussion on economic issues emphasized the possibility of using donated equipment, supplies, and labor to construct artificial reefs. This discussion was based on an actual artificial reef development program for Smith Mountain Lake in Virginia.

Feigenbaum et al. (1989) discuss methodologies, results, and conclusions from a three-year artificial reef study program in the Chesapeake Bay supported by a mitigation fund. The study experimented with various reef structures and sites. The stress levels and stability of the structures were tested by placing them in both the bay and nearby coastal waters. Feigenbaum et al. (1989) also present success rates of the various reef structures and sites for attracting fish populations and increasing catch rates. Recommendations of the best structural types and reef locations were made based on the results of the study.

Knatz (1987) describes three projects under consideration as mitigation for port landfill development in Southern California. One project consists of constructing an artificial reef near the Port of Long Beach under the guidelines of state and federal wildlife agencies. The other two projects under consideration are wetland habitat enhancement projects near the port. The determination of adequate mitigation of a development project and the concept of mitigation banking are discussed. The relative technical concerns and cost estimates are provided for each project.

McGurrin and Fedler (1989) evaluate the planning, siting, and socio-economic impacts associated with the rigs-to-reefs development program, specifically the Tenneco II artificial reef project. This project consisted of transporting three obsolete petroleum platforms from Louisiana to south Florida. The platforms now serve as a large artificial reef site for recreational fishermen.

Smallowitz (1989) discusses the effects that the increasing number of hydroelectric dams in the Northwest have had on the annual runs of salmon and trout. The program to alleviate the injury inflicted on these migrating fish populations was initiated by the Northwest Power Act. The program includes both the enforcement of management practice policies and installation of mechanical fish passageways around or through the dams.

Watt (1986) describes a small liming program established to reduce the effects of acidity on the salmon populations which inhabit several rivers in Nova Scotia. This action could be applicable as off-site mitigation for a discharge. Chemical transportation on the rivers has caused the pH to decline. The restoration action presented as technically feasible in this situation is the addition of limestone to the rivers to counteract the acidic contamination. This same action can also be used on streams and lakes with low pH levels. In addition to describing the liming process, the estimated costs related to this effort and the expected benefits from the liming are presented and discussed.

4.3.2.3 Cost of Restoration Actions

The following paragraphs discuss the estimated costs involved with restoration of fish populations injured or destroyed by hazardous substance contamination. The actions include:

- Natural Recovery;
- Restocking/Replacement;
- Fishery habitat restoration and enhancement;
- Modification of fishery management practices; and
- Habitat protection and acquisition.

4.3.2.3.1 Natural Recovery

Section 4.4 provides a description of the costs of monitoring programs.

4.3.2.3.2 Restocking/Relocation

Two processes must be completed before restocking or relocation can occur. First, the habitat must be restored and free from contamination enough to support any fish or wildlife species reintroduced into the environment. Second, an assessment of the lost fish and wildlife species must be conducted in order to determine the related costs for this restoration option.

This section provides estimated costs associated with the process of restocking various fish species. The costs were obtained from the literature summarized above and are presented here on a per unit basis. These costs and the associated assumptions or considerations are discussed below.

There exist two principal methods of restocking. The trustees can either obtain fish from an established fish hatchery, assuming comparable fish species are readily available from a hatchery and within transportable distance from the restoration area, or develop hatcheries specifically for the purpose of restocking.

The American Fisheries Society handbook (Riely, Southwick, and Reilly, 1990) provides the costs of fish if obtained directly from a hatchery. These costs were developed from a survey of private and public hatcheries throughout the United States. The costs are provided either per fish, per pound of fish, or per inch of fish and are presented in Exhibits 4.13 through 4.19. The costs were calculated, when possible, for each U.S. Fish and Wildlife Service region. Exhibit 4.13 presents the fish values on a national level. When determining costs for specific species, however, the regional tables (Exhibits 4.14 through 4.19) should be consulted first. If the particular species is not listed in the table or the price is not available on a regional level, then the national table should be checked. The six U.S. Fish and Wildlife Service regions are listed below along with the table number that lists the costs for that region and states included in the region.

FWS Region	Exhibit #	States Included
1	4.14	HI, ID, NV, CA, OR, WA
2	4.15	AZ, NM, OK, TX
3	4.16	IL, IN, IA, MI, MN, MO, OH, WI
4	4.17	AL, AR, FL, GA, KY, LA, MS, NC, SC, TN
5	4.18	CT, DE, ME, MD, MA, NH, NJ, NY, PA, RI, VT, VA, WV
6	4.19	CO, KS, MT, NE, ND, SD, UT, WY

Alaska is Region 7, but there are not enough hatcheries from which to determine regional replacement costs.

This handbook also provides general transportation costs for transporting the fish from the hatchery to the point of release. Based on the survey of hatcheries, the average transportation cost is $1.20 per mile.

The U.S. Fish and Wildlife habitat and population improvement handbook (Nelson et al., 1978) provides costs associated with the development of a fish hatchery. The average capital cost of hatchery-raised fish, based on data from three projects and amortized over 20 years, is $2.35 (in mid-1992 dollars) per pound. The annual operation and maintenance cost of fish released from the hatchery, based on data from four projects, is $2.16 (in mid-1992 dollars) per pound. The total annual cost to operate a fish hatchery is thus $4.51 per pound of fish released.

Exhibit 4.13 Estimated costs of restocking various fish species in all U.S. Fish and Wildlife Service Regions (in mid-1992 dollars)

	Cost per fish (unless otherwise stated) by length of restocked fish.															
Order, Family and Species	1 in	2 in	3 in	4 in	5 in	6 in	7 in	8 in	9 in	10 in	11 in	12 in	13 in	14 in	15 in	over 15 in
ACIPENSERIFORMES																
Acipenseridae (Sturgeons)	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$80.28/lb
Acipenser oxyrhynchus (Atlantic sturgeon)	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$80.28/lb
Acipenser medirostris (Green sturgeon)	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$80.28/lb
Acipenser fulvescens (Lake sturgeon)	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$80.28/lb
Scaphirhynchus albus (Pallid sturgeon)	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$80.28/lb
Acipenser brevirostrum (Shortnose sturgeon)	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$80.28/lb
Scaphirhynchus platorynchus (Shovelnose sturgeon)	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$80.28/lb
Acipenser transmontanus (white sturgeon)	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$80.28/lb
Polyodontidae (Paddlefish)																
Polyodon spathula (Paddlefish)	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$35.21/lb
LEPISOSTEIFORMES																
Lepisosteidae (Gars)																
Atractosteus spatula (Alligator gar)	$0.85	$0.85	$0.85	$0.85	$1.06	$1.06	$1.06	$1.49	$1.49	$2.13	$2.13	$2.13	$2.13	$3.19	$3.95	$4.70/lb
Lepisosteus platyrhincus (Florida gar)	$0.85	$0.85	$0.85	$0.85	$1.06	$1.06	$1.06	$1.49	$1.49	$2.13	$2.13	$2.13	$2.13	$3.19	$3.95	$4.70/lb
Lepisosteus osseus (Longnose gar)	$0.85	$0.85	$0.85	$0.85	$1.06	$1.06	$1.06	$1.49	$1.49	$2.13	$2.13	$2.13	$2.13	$3.19	$3.95	$4.70/lb
Lepisosteus platostomus (Shortnose gar)	$0.85	$0.85	$0.85	$0.85	$1.06	$1.06	$1.06	$1.49	$1.49	$2.13	$2.13	$2.13	$2.13	$3.19	$3.95	$4.70/lb
Lepisosteus oculatus (Spotted gar)	$0.85	$0.85	$0.85	$0.85	$1.06	$1.06	$1.06	$1.49	$1.49	$2.13	$2.13	$2.13	$2.13	$3.19	$3.95	$4.70/lb
AMIIFORMES																
Amlidae (Bowfin)																
Amia calva (Bowfin)	$0.31 per pound															
ANGUILLIFORMES																
Anguillidae (Freshwater eels)																
Anguilla rostrata (American eel)	$2.13															
OSTEOGLOSSIFORMES																
Hiodonidae (Mooneyes)																
Hiodon alosoides (Goldeye)	$0.12	$0.12	$0.12	$0.26	$0.26	$0.26	$0.49	$0.49	$0.73	$0.73	$0.82	$0.82	$0.95	$0.95	$0.95	$0.95
Hiodon tergisus (Moodeye)	$0.12	$0.12	$0.12	$0.26	$0.26	$0.26	$0.49	$0.49	$0.73	$0.73	$0.82	$0.82	$0.95	$0.95	$0.95	$0.95
SALMONIFORMES																
Salmonidae (Trouts)																
Salmo salar (Atlantic salmon)	$0.28	$0.31	$0.38	$0.47	$0.50	$0.53	$0.55	$0.72	$0.87	$1.12	$1.46	$2.12	$2.66	$3.30	$3.99	$1.94/lb.
Oncorhynchus tshawytscha (Chinook salmon)	$0.28	$0.31	$0.38	$0.47	$0.50	$0.53	$0.55	$0.72	$0.87	$1.12	$1.46	$2.12	$2.66	$3.30	$3.99	$1.94/lb
Oncorhynchus keta (Chum salmon)	$0.28	$0.31	$0.38	$0.47	$0.50	$0.53	$0.55	$0.72	$0.87	$1.12	$1.46	$2.12	$2.66	$3.30	$3.99	$1.94/lb
Oncorhynchus kisutch (Coho salmon)	$0.28	$0.31	$0.38	$0.47	$0.50	$0.53	$0.55	$0.72	$0.87	$1.12	$1.46	$2.12	$2.66	$3.30	$3.99	$1.94/lb
Oncorhynchus gorbuscha (Pink salmon)	$0.28	$0.31	$0.38	$0.47	$0.50	$0.53	$0.55	$0.72	$0.87	$1.12	$1.46	$2.12	$2.66	$3.30	$3.99	$1.94/lb
Oncorhynchus nerka (Sockeye salmon)	$0.28	$0.31	$0.38	$0.47	$0.50	$0.53	$0.55	$0.72	$0.87	$1.12	$1.46	$2.12	$2.66	$3.30	$3.99	$1.94/lb
Salvelinus alpinus (Arctic char)	$0.16	$0.22	$0.31	$0.41	$0.44	$0.48	$0.71	$0.90	$1.14	$1.49	$1.70	$2.02	$2.33	$2.83	$2.93	$1.67/lb
Thymallus articus (Arctic grayling)	$0.16	$0.22	$0.31	$0.41	$0.44	$0.48	$0.71	$0.90	$1.14	$1.49	$1.70	$2.02	$2.33	$2.83	$2.93	$1.67/lb
Coregonus spp. (Cisco)	$0.16	$0.22	$0.31	$0.41	$0.44	$0.48	$0.71	$0.90	$1.14	$1.49	$1.70	$2.02	$2.33	$2.83	$2.93	$1.67/lb
Salvelinus fontinalis (Brook trout)	$0.16	$0.22	$0.31	$0.41	$0.44	$0.48	$0.71	$0.90	$1.14	$1.49	$1.70	$2.02	$2.33	$2.83	$2.93	$1.67/lb

Order, Family and Species	Cost per fish (unless otherwise stated) by length of restocked fish.														
	1 in	2 in	3 in	4 in	5 in	6 in	7 in	8 in	9 in	10 in	11 in	12 in	13 in	14 in	15 in	over 15 in
Salmo trutta (Brown trout)	$0.16	$0.22	$0.31	$0.41	$0.44	$0.48	$0.71	$0.90	$1.14	$1.49	$1.70	$2.02	$2.33	$2.83	$2.93	$1.67/lb
Oncorhynchus clarki (Cutthroat trout)	$0.16	$0.22	$0.31	$0.41	$0.44	$0.48	$0.71	$0.90	$1.14	$1.49	$1.70	$2.02	$2.33	$2.83	$2.93	$1.67/lb
Salvelinus namaycush (Lake trout)	$0.16	$0.22	$0.31	$0.41	$0.44	$0.48	$0.71	$0.90	$1.14	$1.49	$1.70	$2.02	$2.33	$2.83	$2.93	$1.67/lb
Prosopium spp. (whitefish)	$0.16	$0.22	$0.31	$0.41	$0.44	$0.48	$0.71	$0.90	$1.14	$1.49	$1.70	$2.02	$2.33	$2.83	$2.93	$1.67/lb
Oncorhynchus mykiss (Rainbow trout)	$0.12	$0.18	$0.20	$0.27	$0.34	$0.43	$0.57	$0.71	$0.95	$1.49	$1.70	$2.02	$2.33	$2.83	$2.93	$1.67/lb
Umbridae (Mudminnows)										$1.28	$1.38	$1.76	$2.20	$2.57	$2.89	$1.65/lb
Umbra spp. (Mudminnow)	$0.09 per pound															
Esocidae (Pikes)																
Esox niger Chain pickerel	$0.14	$0.30	$0.51	$0.85	$0.85	$0.85	$1.19	$1.19	$1.70	$1.70	$1.70	$1.70	$2.79 per pound			
Esox americanus vermiculatus (Grass pickerel)	$0.14	$0.30	$0.51	$0.85	$0.85	$0.85	$1.19	$1.19	$1.70	$1.70	$1.70	$1.70	$2.79 per pound			
Esox lucius (Northern pike)	$0.14	$0.30	$0.51	$0.85	$0.85	$0.85	$1.19	$1.19	$1.70	$1.70	$1.70	$1.70	$2.79 per pound			
Esox americanus americanus (Redfin pickerel)	$0.14	$0.30	$0.51	$0.85	$0.85	$0.85	$1.19	$1.19	$1.70	$1.70	$1.70	$1.70	$2.79 per pound			
Esox masquinongy (Muskellunge)	$1.28	$3.72	$6.38	$7.45	$9.31	$9.79	$12.62	$15.14	$16.76	$19.15	$33.14/per pound					
Esox lucius/masquinongy (Tiger muskellunge)	$1.28	$3.72	$6.38	$7.45	$9.31	$9.79	$12.62	$15.14	$16.76	$19.15	$33.14/per pound					
CYPRINIFORMES																
Characidae (Characins)																
Astyanax mexicanus (Mexican tetra)	$0.09															
Cyprinidae (Minnows and Carps)																
Cyprinus carpio (Common carp)	$0.09	$0.09	$0.09	$0.09	$0.09	$0.09	$0.16	$0.16	$0.19	$0.24	$0.29	$0.29 per pound				
Campostoma spp. (Stoneroller)	$0.09	$0.09	$0.09	$0.09	$0.09	$0.09	$0.16	$0.19	$0.24	$0.29	$0.29	$0.29 per pound				
Pimephales promelas (Fathead minnow)	$0.01															
Notemigonus crysoleucas (Golden shiner)	$0.20	$0.20	$0.20	$0.20	$0.30	$0.30	$3.46 per pound									
Cterlopharyrlgodon idella (Grass carp)	$0.37	$0.74	$0.74	$1.50	$2.62	$2.62	$2.62	$3.60					$3.60 per pound			
Other cyprinids	$0.09															
Ictiobus cyprinellus (Bigmouth buffalo)	$0.14	$0.14	$0.14	$0.14	$0.24	$0.24	$0.32	$0.32	$0.32	$0.44	$0.51	$0.63	$0.63 per pound			
Ictiobus niger (Black buffalo)	$0.14	$0.14	$0.14	$0.14	$0.24	$0.24	$0.32	$0.32	$0.32	$0.44	$0.51	$0.63	$0.63 per pound			
Ictiobus babalus (Smallmouth buffalo)	$0.14	$0.14	$0.14	$0.14	$0.24	$0.24	$0.32	$0.32	$0.32	$0.44	$0.51	$0.63	$0.63 per pound			
Hypentelium etowanum (Alabama hog sucker)	$0.37	$0.37	$0.85	$0.85	$0.85	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	$2.42 per pound		
Moxostoma duquesnei (Black redhorse)	$0.37	$0.37	$0.85	$0.85	$0.85	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	$2.42 per pound		
Moxostoma poecilurum (Blacktail redhorse)	$0.37	$0.37	$0.85	$0.85	$0.85	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	$2.42 per pound		
Cycleptus elongatus (Blue sucker)	$0.37	$0.37	$0.85	$0.85	$0.85	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	$2.42 per pound		
Erimyzon oblongus (Creek chubsucker)	$0.37	$0.37	$0.85	$0.85	$0.85	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	$2.42 per pound		
Moxostoma erythrurum (Golden redhorse)	$0.37	$0.37	$0.85	$0.85	$0.85	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	$2.42 per pound		
Erimyzon sucetta (Lake chubsucker)	$0.37	$0.37	$0.85	$0.85	$0.85	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	$2.42 per pound		
Catostomus catostomus (Longnose sucker)	$0.37	$0.37	$0.85	$0.85	$0.85	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	$2.42 per pound		
Catostomus platyrhynchus (Mountain sucker)	$0.37	$0.37	$0.85	$0.85	$0.85	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	$2.42 per pound		
Hypentelium nigricans (Northern hog sucker)	$0.37	$0.37	$0.85	$0.85	$0.85	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	$2.42 per pound		
Moxostoma carinatum (River redhorse)	$0.37	$0.37	$0.85	$0.85	$0.85	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	$2.42 per pound		
Moxostoma macrolepidotum (shorthead redhorse,	$0.37	$0.37	$0.85	$0.85	$0.85	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	$2.42 per pound		
Moxostoma anisurum (Silver redhorse)	$0.37	$0.37	$0.85	$0.85	$0.85	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	$2.42 per pound		
Minytrema melanops (spotted sucker)	$0.37	$0.37	$0.85	$0.85	$0.85	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	$2.42 per pound		
Catostomus comnersoni (w'hite sucker)	$0.37	$0.37	$0.85	$0.85	$0.85	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	$2.42 per pound		
Carpiodes cyprinus (Quillback)	$0.06	$0.06	$0.06	$0.07	$0.07	$0.07	$0.14	$0.14	$0.18	$0.18	$0.24	$0.29	$0.29 per pound			
Carpiodes carpio (River carpsucker)	$0.06	$0.06	$0.06	$0.07	$0.07	$0.07	$0.14	$0.14	$0.18	$0.18	$0.24	$0.29	$0.29 per pound			

Order, Family and Species	Cost per fish (unless otherwise stated) by length of restocked fish.															
	1 in	2 in	3 in	4 in	5 in	6 in	7 in	8 in	9 in	10 in	11 in	12 in	13 in	14 in	15 in	over 15 in
SILURIFORMES																
Ictaluridae (Freshwater catfish)																
Ictalurus furcatus (Blue catfish)	$0.19	$0.23	$0.24	$0.26	$0.29	$0.41	$0.44	$0.52	$0.71	$0.77	$0.84	$1.20	$1.56	$1.96	$1.17 per pound	
Ictalurus punctatus (Channel catfish)	$0.19	$0.23	$0.24	$0.26	$0.29	$0.41	$0.44	$0.52	$0.71	$0.77	$0.84	$1.20	$1.56	$1.96	$1.17 per pound	
Pylodictus olivaris (Flathead catfish)	$0.19	$0.23	$0.24	$0.26	$0.29	$0.41	$0.44	$0.52	$0.71	$0.77	$0.84	$1.20	$1.56	$1.96	$1.17 per pound	
Ictalurus catus (white catfish)	$0.19	$0.23	$0.24	$0.26	$0.29	$0.41	$0.44	$0.52	$0.71	$0.77	$0.84	$1.20	$1.56	$1.96	$1.17 per pound	
Ictalurus melas (Black bullhead)	$0.53	$0.53	$0.80	$0.80	$1.33	$17.44 per pound										
Ictalurus nebulosus (Brown bullhead)	$0.53	$0.53	$0.80	$0.80	$1.33	$17.44 per pound										
Ictalurus platycephalus (Flat bullhead)	$0.53	$0.53	$0.80	$0.80	$1.33	$17.44 per pound										
Noturus spp. (Madtoms)	$0.53	$0.53	$0.80	$0.80	$1.33	$17.44 per pound										
Ictalurus natalis (Yellow bullhead)	$0.53	$0.53	$0.80	$0.80	$1.33	$17.44 per pound										
Aphredoderus sayanus (Pirate perch)	$0.09															
Percopsis omiscomaycus (Trout-perch)	$0.09															
ATHERINIFORMES																
Cyprinidonitae (Killifishes)																
Fundulus spp.(Killifish, topminnows, studfish	$0.09															
Poeciliidae (Livebearers)																
Gambusia affinis (Mosquitofish)	$0.09															
Atherinidae (Silversides)																
Labidesthes sicculus (Brook silverside	$0.09															
Menidia beryllina (Inland silverside)	$0.09															
Menidia extensa (Waccamaw silverside)	$0.09															
GASTEROSTEIFORMES																
Gasterosteidae (Sticklebacks)																
Apeltes quadracus (4-spine stickleback)	$0.09															
Gasterosteus aculeatus (3-spine stickleback)	$0.09															
PERCIFORMES																
Percichthyidae (Temperate basses)																
Morone saxatilis (Striped bass)	$0.17	$0.31	$0.47	$0.64	$0.92	$0.92	$1.24	$1.46	$1.65	$1.82	$2.13	$2.73	$2.60 per pound			
Morone chrysops (white bass)	$0.16	$0.32	$0.48	$0.64	$0.80	$0.96	$1.12	$1.44	$1.44	$1.60	$1.76	$1.92	$1.22 per pound			
Morone mississippiensis (Yellow bass)	$0.16	$0.32	$0.48	$0.64	$0.80	$0.96	$1.12	$1.44	$1.44	$1.60	$1.76	$1.92	$1.22 per pound			
Monone americana (white perch)	$0.12	$0.19	$0.32	$0.40	$0.60	$0.70	$0.82	$0.95	$1.06	$1.18	$1.31	$1.40	$1.40 per pound			
Centrarchidae (Sunfishes)																
Micropterus salmoides (Largemouth bass)	$0.24	$0.34	$0.55	$0.76	$1.34	$1.67	$2.42	$2.97	$3.71	$3.98	$4.23	$4.28	$4.12 per pound			
Micropterus coosae (Redeye bass)	$0.24	$0.34	$0.55	$0.76	$1.34	$1.67	$2.42	$2.97	$3.71	$3.98	$4.23	$4.28	$4.12 per pound			
Micropterus punctulatus (Spotted bass)	$0.24	$0.34	$0.55	$0.76	$1.34	$1.67	$2.42	$2.97	$3.71	$3.98	$4.23	$4.28	$4.12 per pound			
Micropterus dolomieui (Smallmouth bass)	$0.70	$0.70	$1.45	$1.64	$2.14	$2.63	$3.17	$5.09	$6.54	$6.54	$8.51	$8.51	$8.51	$4.77 per pound		
Pomoxis nigromaculatus (Black crappie)	$0.16	$0.29	$0.39	$0.49	$0.73	$0.76	$0.90	$1.22	$3.92 per pound							
Pomoxis annularis (white crappie)	$0.16	$0.29	$0.32	$0.44	$0.73	$0.76	$0.90	$1.22	$3.92 per pound							
Felassoma zonatum (Banded pygmy sunfish)	$0.17	$0.20	$0.32	$0.44	$0.59	$0.88	$0.92	$1.19	$1.60	$2.43 per pound						
Enneacanthus obesus (Banded sunfish)	$0.17	$0.20	$0.32	$0.44	$0.59	$0.88	$0.92	$1.19	$1.60	$2.43 per pound						
Lepomis macrochirus (Bluegill)	$0.17	$0.20	$0.32	$0.44	$0.59	$0.88	$0.92	$1.19	$1.60	$2.43 per pound						
Enneacanthus gloriosus (Bluespotted sunfish)	$0.17	$0.20	$0.32	$0.44	$0.59	$0.88	$0.92	$1.19	$1.60	$2.43 per pound						
Lepomis marginatus (Dollar sunfish)	$0.17	$0.20	$0.32	$0.44	$0.59	$0.88	$0.92	$1.19	$1.60	$2.43 per pound						

	Cost per fish (unless otherwise stated) by length of restocked fish.															
Order, Family and Species	1 in	2 in	3 in	4 in	5 in	6 in	7 in	8 in	9 in	10 in	11 in	12 in	13 in	14 in	15 in	over 15 in
Centrarchus macropterus (Flier)	$0.17	$0.20	$0.32	$0.44	$0.59	$0.88	$0.92	$1.19	$1.60	$2.43 per pound						
Lepomis cyanellus (Green sunfish)	$0.17	$0.20	$0.32	$0.44	$0.59	$0.88	$0.92	$1.19	$1.60	$2.43 per pound						
Lepomis megalotis (Longear sunfish)	$0.17	$0.20	$0.32	$0.44	$0.59	$0.88	$0.92	$1.19	$1.60	$2.43 per pound						
Lepomis humilis (Orangespotted sunfish)	$0.17	$0.20	$0.32	$0.44	$0.59	$0.88	$0.92	$1.19	$1.60	$2.43 per pound						
Lepomis gibbosus (Pumpkinseed)	$0.17	$0.20	$0.32	$0.44	$0.59	$0.88	$0.92	$1.19	$1.60	$2.43 per pound						
Lepomis auritus (Redbreast sunfish)	$0.17	$0.20	$0.32	$0.44	$0.59	$0.88	$0.92	$1.19	$1.60	$2.43 per pound						
Lepomis microlophus (Redear sunfish)	$0.17	$0.20	$0.32	$0.44	$0.59	$0.88	$0.92	$1.19	$1.60	$2.43 per pound						
Ambloplites rupestris (Rock bass)	$0.17	$0.20	$0.32	$0.44	$0.59	$0.88	$0.92	$1.19	$1.60	$2.43 per pound						
Ambloplites ariommus (Shadow bass)	$0.17	$0.20	$0.32	$0.44	$0.59	$0.88	$0.92	$1.19	$1.60	$2.43 per pound						
Lepomis punctatus (Spotted sunfish)	$0.17	$0.20	$0.32	$0.44	$0.59	$0.88	$0.92	$1.19	$1.60	$2.43 per pound						
Lepomis gulosus (warmouth)	$0.17	$0.20	$0.32	$0.44	$0.59	$0.88	$0.92	$1.19	$1.60	$2.43 per pound						
Perca flavenscens (Yellow perch)	$0.30	$0.49	$0.80	$1.03	$1.45	$1.59	$2.00	$9.57 per pound								
Etheostoma spp.; Percina spp. (Darters)	$0.30	$0.49	$0.80	$1.03	$1.45	$1.59	$2.00	$9.57 per pound								
Stizostedion canadense (Sauger)	$0.27	$0.36	$0.81	$0.99	$1.54	$1.94	$2.67	$3.02	$3.30	$3.69	$4.56	$5.55	$9.21	$11.40	$13.78	$6.69/lb
Stizostedion vitreum vitreum (walleye)	$0.27	$0.36	$0.81	$0.99	$1.54	$1.94	$2.67	$3.02	$3.30	$3.69	$4.56	$5.55	$9.21	$11.40	$13.78	$6.69/lb
Aplodinotus grunniens (Freshwater drum)	$0.12			$0.19			$0.29		$0.40			$0.48	$0.55	$0.55 per pound		
Cichlidae (Cichlids)																
Tilapia melanotheron (Blackchin tilapia)	$0.07	$0.07	$0.15	$0.15	$0.22	$0.22	$0.27	$0.30	$0.33	$0.37	$0.41	$0.45	$0.45 per pound			
Tilapia aurea (Blue tilapia)	$0.07	$0.07	$0.15	$0.15	$0.22	$0.22	$0.27	$0.30	$0.33	$0.37	$0.41	$0.45	$0.45 per pound			
Tilapia mossambica (Mozambique tilapia)	$0.07	$0.07	$0.15	$0.15	$0.22	$0.22	$0.27	$0.30	$0.33	$0.37	$0.41	$0.45	$0.45 per pound			
Tilapia zilli (Redbelly tilapia)	$0.07	$0.07	$0.15	$0.15	$0.22	$0.22	$0.27	$0.30	$0.33	$0.37	$0.41	$0.45	$0.45 per pound			
Tilapia mariae (Spotted tilapia)	$0.07	$0.07	$0.15	$0.15	$0.22	$0.22	$0.27	$0.30	$0.33	$0.37	$0.41	$0.45	$0.45 per pound			
Cottidae (Sculpins)																
Cottus spp. (Sculpin)	$0.09															

* For Fish longer than 30 inches
Source: American Fisheries Society, 1990

Exhibit 4.14 Estimated costs of restocking various fish species in U.S. Fish and Wildlife Service Region 1 (in mid-1992 dollars).

	Cost per fish (unless otheriwse stated) by length of restock fish.															
Order, Family and Species	**1 in**	**2 in**	**3 in**	**4 in**	**5 in**	**6 in**	**7 in**	**8 in**	**9 in**	**10 in**	**11 in**	**12 in**	**13 in**	**14 in**	15 in	over 15 inches
SALMONIFORMES																
Salmonidae (Trouts)																
Salmo salar (Atlantic salmon)	$0.28	$0.35	$0.38	$0.49	$0.52	$0.55	$0.57	$0.65	$0.95	$1.04	$1.37	$1.78	$2.23	$2.76	$3.34	N/A
Oncorhynchus tsha~ytscha (Chinook salmon)	$0.28	$0.35	$0.38	$0.49	$0.52	$0.55	$0.57	$0.65	$0.95	$1.04	$1.37	$1.78	$2.23	$2.76	$3.34	N/A
Oncorhynchus keta (Chum salmon)	$0.28	$0.35	$0.38	$0.49	$0.52	$0.55	$0.57	$0.65	$0.95	$1.04	$1.37	$1.78	$2.23	$2.76	$3.34	N/A
Oncorhynchus kisutch (Coho salmon)	$0.28	$0.35	$0.38	$0.49	$0.52	$0.55	$0.57	$0.65	$0.95	$1.04	$1.37	$1.78	$2.23	$2.76	$3.34	N/A
Oncorhynchus gorbuscha (Pink salmon)	$0.28	$0.35	$0.38	$0.49	$0.52	$0.55	$0.57	$0.65	$0.95	$1.04	$1.37	$1.78	$2.23	$2.76	$3.34	N/A
Oncorhynchus nerka (Sockeye salmon)	$0.28	$0.35	$0.38	$0.49	$0.52	$0.55	$0.57	$0.65	$0.95	$1.04	$1.37	$1.78	$2.23	$2.76	$3.34	N/A
Oncorhynchus mykiss (Rainbow trout)	$0.09	$0.12	$0.17	$0.22	$0.30	$0.33	$0.35	$0.53	$0.76	$1.29	$1.83	$2.36	$3.00	$3.81	$4.53	N/A

NA = The regional fish value is not available. Refer to Table 3.12 for the national value.
Source: American Fisheries Society, 1990

Exhibit 4.15 Estimated costs of restocking various fish species in U.S. Fish and Wildlife Service Region 2 (in mid-1992 dollars).

	Cost per fish (unless otherwise stated) by length of restocked fish.															
Order, Family, and Species	1 in	2 in	3 in	4 in	5 in	6 in	7 in	8 in	9 in	10 in	11 in	12 in	13 in	14 in	15	Over 15 in
SALMONIFORMES																
Salmonidae (Trouts)																
Salvelinus alpinus (Arctic char)	$0.13	$0.26	$0.36	$0.49	$0.62	$0.74	$0.87	NA	NA	NA	NA	NA	NA	NA	NA	NA
Thymallus articus (Arctic grayling)	$0.13	$0.26	$0.36	$0.49	$0.62	$0.74	$0.87	NA	NA	NA	NA	NA	NA	NA	NA	NA
Coregonus spp. (Cisco)	$0.13	$0.26	$0.36	$0.49	$0.62	$0.74	$0.87	NA	NA	NA	NA	NA	NA	NA	NA	NA
Salvelinus fontinalis (Brook trout)	$0.13	$0.26	$0.36	$0.49	$0.62	$0.74	$0.87	NA	NA	NA	NA	NA	NA	NA	NA	NA
Salmo trutta (Brown trout)	$0.13	$0.26	$0.36	$0.49	$0.62	$0.74	$0.87	NA	NA	NA	NA	NA	NA	NA	NA	NA
Oncorhynchus clarki (Cutthroat trout)	$0.13	$0.26	$0.36	$0.49	$0.62	$0.74	$0.87	NA	NA	NA	NA	NA	NA	NA	NA	NA
Salvelinus namaycush (Lake trout)	$0.13	$0.26	$0.36	$0.49	$0.62	$0.74	$0.87	NA	NA	NA	NA	NA	NA	NA	NA	NA
Prosopium spp. (whitefish)	$0.13	$0.26	$0.36	$0.49	$0.62	$0.74	$0.87	NA	NA	NA	NA	NA	NA	NA	NA	NA
Oncorhynchus mykiss (Rainbow trout)	$0.13	$0.26	$0.36	$0.49	$0.62	$0.74	$0.87	NA	NA	NA	NA	NA	NA	NA	NA	NA
CYPRINIFORMES																
Cyprinidae (Minnows and Carps)																
Hypentelium etowanum (Alabama hog sucker)	NA	NA	$1.06	$1.06	$1.06	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	NA	NA	NA
Moxostoma duquesnei (Black redhorse)	NA	NA	$1.06	$1.06	$1.06	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	NA	NA	NA
Moxostoma poecilurum (Blacktail redhorse)	NA	NA	$1.06	$1.06	$1.06	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	NA	NA	NA
Cycleptus elongatus (Blue sucker)	NA	NA	$1.06	$1.06	$1.06	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	NA	NA	NA
Erimyzon oblongus (Creek chubsucker)	NA	NA	$1.06	$1.06	$1.06	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	NA	NA	NA
Moxostoma erythrurum (Golden redhorse)	NA	NA	$1.06	$1.06	$1.06	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	NA	NA	NA
Erimyzon sucetta (Lake chubsucker)	NA	NA	$1.06	$1.06	$1.06	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	NA	NA	NA
Catostomus catostomus (Longnose sucker)	NA	NA	$1.06	$1.06	$1.06	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	NA	NA	NA
Catostomus platyrhynchus (Mountain sucker)	NA	NA	$1.06	$1.06	$1.06	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	NA	NA	NA
Hypentelium nigricans (Northern hog sucker)	NA	NA	$1.06	$1.06	$1.06	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	NA	NA	NA
Moxostoma carinatum (River redhorse)	NA	NA	$1.06	$1.06	$1.06	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	NA	NA	NA
Moxostoma macrolepidotum (Shorthead redhorse)	NA	NA	$1.06	$1.06	$1.06	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	NA	NA	NA
Moxostoma anisurum (Silver redhorse)	NA	NA	$1.06	$1.06	$1.06	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	NA	NA	NA
Minytrema melanops (Spotted sucker)	NA	NA	$1.06	$1.06	$1.06	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	NA	NA	NA
Catostomus commersoni (white sucker)	NA	NA	$1.06	$1.06	$1.06	$1.06	$2.13	$2.13	$2.13	$2.13	$2.13	$2.13	$3.19	NA	NA	NA

Exhibit 4.16 Estimated costs of restocking various fish species in U.S. Fish and Wildlife Service Region 3 (in mid-1992 dollars).

	Cost per fish (unless otherwise stated) by length of restocked fish.															
	1 in	2 in	3 in	4 in	5 in	6 in	7 in	8 in	9 in	10 in	11 in	12 in	13 in	14 in	15 in	over 15 in
SALMONIFORMES																
Salmonidae (Trouts)																
Salmo salar (Atlantic salmon)	NA	$0.09	$0.28	$0.29	$0.31	$0.55	$0.63	$0.81	$1.81	$2.45	$3.21	$4.13	$5.27	$6.56	$7.92	NA
Oncorhynchus tshawytscha (Chinook salmon)	NA	$0.09	$0.28	$0.29	$0.31	$0.55	$0.63	$0.81	$1.81	$2.45	$3.21	$4.13	$5.27	$6.56	$7.92	NA
Oncorhynchus keta (Chum salmon)	NA	$0.09	$0.28	$0.29	$0.31	$0.55	$0.63	$0.81	$1.81	$2.45	$3.21	$4.13	$5.27	$6.56	$7.92	NA
Oncorhynchus kisutch (Coho salmon)	NA	$0.09	$0.28	$0.29	$0.31	$0.55	$0.63	$0.81	$1.81	$2.45	$3.21	$4.13	$5.27	$6.56	$7.92	NA
Oncorhynchus gorbuscha (Pink salmon)	NA	$0.09	$0.28	$0.29	$0.31	$0.55	$0.63	$0.81	$1.81	$2.45	$3.21	$4.13	$5.27	$6.56	$7.92	NA
Oncorhynchus nerka (Sockeye salmon)	NA	$0.09	$0.28	$0.29	$0.31	$0.55	$0.63	$0.81	$1.81	$2.45	$3.21	$4.13	$5.27	$6.56	$7.92	NA
Salvelinus alpinus (Arctic char)	$0.21	$0.26	$0.30	$0.34	$0.38	$0.43	$0.50	$0.65	$0.81	$1.05	$1.20	$1.23	$1.56	$1.95	$2.31	NA
Thymallus articus (Arctic grayling)	$0.21	$0.26	$0.30	$0.34	$0.38	$0.43	$0.50	$0.65	$0.81	$1.05	$1.20	$1.23	$1.56	$1.95	$2.31	NA
Coregonus spp. (Cisco)	$0.21	$0.26	$0.30	$0.34	$0.38	$0.43	$0.50	$0.65	$0.81	$1.05	$1.20	$1.23	$1.56	$1.95	$2.31	NA
Salvelinus fontinalis (Brook trout)	$0.21	$0.26	$0.30	$0.34	$0.38	$0.43	$0.50	$0.65	$0.81	$1.05	$1.20	$1.23	$1.56	$1.95	$2.31	NA
Salmo trutta (Bro~n trout)	$0.21	$0.26	$0.30	$0.34	$0.38	$0.43	$0.50	$0.65	$0.81	$1.05	$1.20	$1.23	$1.56	$1.95	$2.31	NA
Oncorhynchus clarki (Cutthroat trout)	$0.21	$0.26	$0.30	$0.34	$0.38	$0.43	$0.50	$0.65	$0.81	$1.05	$1.20	$1.23	$1.56	$1.95	$2.31	NA
Salvelinus namaycush (Lake trout)	$0.21	$0.26	$0.30	$0.34	$0.38	$0.43	$0.50	$0.65	$0.81	$1.05	$1.20	$1.23	$1.56	$1.95	$2.31	NA
Prosopium spp. (Whitefish)	$0.21	$0.26	$0.30	$0.34	$0.38	$0.43	$0.50	$0.65	$0.81	$1.05	$1.20	$1.23	$1.56	$1.95	$2.31	NA
Oncorhynchus mykiss (Rainbow trout)	$0.11	$0.16	$0.17	$0.22	$0.29	$0.45	$0.46	$0.66	$0.88	$1.11	$1.33	$1.55	$1.79	$2.05	$3.17	NA
Esocidae (Pikes)																
Esox niger Chain pickerel	$0.16	$0.27	$0.51	$0.85	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Esox americanus vermiculatus (Grass pickerel)	$0.16	$0.27	$0.51	$0.85	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Esox lucius (Northern pike)	$0.16	$0.27	$0.51	$0.85	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Esox americanus americanus (Redfin pickerel)	$0.16	$0.27	$0.51	$0.85	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Esox masquinongy (Muskellunge)	$1.60	$3.19	$5.52	$6.38	$7.98	$8.38	$10.33	$12.40	$14.36	$17.02	NA	NA	NA	NA	NA	NA
Esox lucius/masquinongy (Tiger muskellunge)	$1.60	$3.19	$5.52	$6.38	$7.98	$8.38	$10.33	$12.40	$14.36	$17.02	NA	NA	NA	NA	NA	NA
SILURIFORMES																
Ictaluridae (Freshwater catfish)																
Ictalurus furcatus (Blue catfish)	$0.03	$0.14	$0.19	$0.19	$0.26	$0.46	$0.51	$0.56	$0.66	$0.71	$0.79	$1.13	$1.47	$1.84	NA	NA
Ictalurus punctatus (Channel catfish)	$0.03	$0.14	$0.19	$0.19	$0.26	$0.46	$0.51	$0.56	$0.66	$0.71	$0.79	$1.13	$1.47	$1.84	NA	NA
Pylodictus olivaris (Flathead catfish)	$0.03	$0.14	$0.19	$0.19	$0.26	$0.46	$0.51	$0.56	$0.66	$0.71	$0.79	$1.13	$1.47	$1.84	NA	NA
Ictalurus catus (White catfish)	$0.03	$0.14	$0.19	$0.19	$0.26	$0.46	$0.51	$0.56	$0.66	$0.71	$0.79	$1.13	$1.47	$1.84	NA	NA
PERCIFORMES																NA
Percichthyidae (Temperate basses)																
Morone saxatilis (Striped bass)	$0.22	$0.65	$0.99	$2.50	$2.98	$2.98	$3.82	$3.90	$5.59	$5.59	NA	NA	NA	NA	NA	NA
Centrarchidae (Sunfishes)																
Micropterus salmoides (Largemouth bass)	$0.14	$0.36	$0.56	$0.66	$0.95	$1.34	$1.56	$2.22	$2.71	$2.71	$2.71	$2.71	NA	NA	NA	NA
Micropterus coosae (Redeye bass)	$0.14	$0.36	$0.56	$0.66	$0.95	$1.34	$1.56	$2.22	$2.71	$2.71	$2.71	$2.71	NA	NA	NA	NA
Micropterus punctulatus (Spotted bass)	$0.14	$0.36	$0.56	$0.66	$0.95	$1.34	$1.56	$2.22	$2.71	$2.71	$2.71	$2.71	NA	NA	NA	NA

	Cost per fish (unless otherwise stated) by length of restocked fish.															
	1 in	2 in	3 in	4 in	5 in	6 in	7 in	8 in	9 in	10 in	11 in	12 in	13 in	14 in	15 in	over 15 in
Micropterus dolomieui (Smallmouth bass)	NA	$0.68	$1.03	$1.38	$1.52	$3.03	$3.03	$6.70	$6.70	$6.70	NA	NA	NA	NA	NA	NA
Pomoxis nigromaculatus (Black crappie)	$0.11	$0.35	$0.39	$0.48	$0.53	$0.85	$0.90	$1.22	NA	NA	NA	NA	NA	NA	NA	NA
Pomoxis annularis (white crappie)	$0.11	$0.35	$0.39	$0.48	$0.53	$0.85	$0.90	$1.22	NA	NA	NA	NA	NA	NA	NA	NA
Felassoma zonatum (Banded pygmy sunfish)	$0.20	$0.27	$0.32	$0.38	$0.49	$0.72	$0.86	$1.05	NA	NA	NA	NA	NA	NA	NA	NA
Enneacanthus obesus (Banded sunfish)	$0.20	$0.27	$0.32	$0.38	$0.49	$0.72	$0.86	$1.05	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis macrochirus (Bluegill)	$0.20	$0.27	$0.32	$0.38	$0.49	$0.72	$0.86	$1.05	NA	NA	NA	NA	NA	NA	NA	NA
Enneacanthus gloriosus (Bluespotted sunfish)	$0.20	$0.27	$0.32	$0.38	$0.49	$0.72	$0.86	$1.05	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis marginatus (Dollar sunfish)	$0.20	$0.27	$0.32	$0.38	$0.49	$0.72	$0.86	$1.05	NA	NA	NA	NA	NA	NA	NA	NA
Centrarchus macropterus (Flier)	$0.20	$0.27	$0.32	$0.38	$0.49	$0.72	$0.86	$1.05	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis cyanellus (Green sunfish)	$0.20	$0.27	$0.32	$0.38	$0.49	$0.72	$0.86	$1.05	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis megalotis (Longear sunfish)	$0.20	$0.27	$0.32	$0.38	$0.49	$0.72	$0.86	$1.05	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis humilis (Orangespotted sunfish)	$0.20	$0.27	$0.32	$0.38	$0.49	$0.72	$0.86	$1.05	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis gibbosus (Pumpkinseed)	$0.20	$0.27	$0.32	$0.38	$0.49	$0.72	$0.86	$1.05	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis auritus (Redbreast sunfish)	$0.20	$0.27	$0.32	$0.38	$0.49	$0.72	$0.86	$1.05	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis microlophus (Redear sunfish)	$0.20	$0.27	$0.32	$0.38	$0.49	$0.72	$0.86	$1.05	NA	NA	NA	NA	NA	NA	NA	NA
Ambloplites rupestris (Rock bass)	$0.20	$0.27	$0.32	$0.38	$0.49	$0.72	$0.86	$1.05	NA	NA	NA	NA	NA	NA	NA	NA
Ambloplites ariommus (Shadow bass)	$0.20	$0.27	$0.32	$0.38	$0.49	$0.72	$0.86	$1.05	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis punctatus (Spotted sunfish)	$0.20	$0.27	$0.32	$0.38	$0.49	$0.72	$0.86	$1.05	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis gulosus (Warmouth)	$0.20	$0.27	$0.32	$0.38	$0.49	$0.72	$0.86	$1.05	NA	NA	NA	NA	NA	NA	NA	NA
Perca flavenscens (Yellow perch)	NA	$0.37	$0.46	$0.53	$0.53	$0.80	$0.80	NA	NA	NA	NA	NA	NA	NA	NA	NA
Etheostoma spp.; Percina spp. (Darters)	NA	$0.37	$0.46	$0.53	$0.53	$0.80	$0.80	NA	NA	NA	NA	NA	NA	NA	NA	NA
Stizostedion canadense (Sauger)	$0.13	$0.33	$0.79	$0.95	$1.27	$1.35	$1.44	$1.89	$2.27	$2.53	$3.66	$4.61	$9.21	$11.40	$13.78	NA
Stizostedion vitreum vitreum (Walleye)	$0.13	$0.33	$0.79	$0.95	$1.27	$1.35	$1.44	$1.89	$2.27	$2.53	$3.66	$4.61	$9.21	$11.40	$13.78	NA

* For Fish longer than 30 inches
Source: American Fisheries Society, 1990

Exhibit 4.17 Estimated costs of restocking various fish species in U.S. Fish and Wildilfe Service Region 4 (in mid-1992 dollars).

	Cost per fish (unless otherwise stated) by length of restocked fish.															
Order, Family and Species	1 in	2 in	3 in	4 in	5 in	6 in	7 in	8 in	9 in	10 in	11 in	12 in	13 in	14 in	15 in	over 15 in
SALMONIFORMES																
Salmonidae (Trouts)																
Salvelinus alpinus (Arctic char)	NA	$0.01	$0.02	$0.07	$0.10	$0.18	$0.27	$0.27	$0.33	$0.39	$0.52	$0.65	$0.81	$1.01	$1.22	NA
Thymallus articus (Arctic grayling)	NA	$0.01	$0.02	$0.07	$0.10	$0.18	$0.27	$0.27	$0.33	$0.39	$0.52	$0.65	$0.81	$1.01	$1.22	NA
Coregonus spp. (Cisco)	NA	$0.01	$0.02	$0.07	$0.10	$0.18	$0.27	$0.27	$0.33	$0.39	$0.52	$0.65	$0.81	$1.01	$1.22	NA
Salvelinus fontinalis (Brook trout)	NA	$0.01	$0.02	$0.07	$0.10	$0.18	$0.27	$0.27	$0.33	$0.39	$0.52	$0.65	$0.81	$1.01	$1.22	NA
Salmo trutta (Brown trout)	NA	$0.01	$0.02	$0.07	$0.10	$0.18	$0.27	$0.27	$0.33	$0.39	$0.52	$0.65	$0.81	$1.01	$1.22	NA
Oncorhynchus clarki (Cutthroat trout)	NA	$0.01	$0.02	$0.07	$0.10	$0.18	$0.27	$0.27	$0.33	$0.39	$0.52	$0.65	$0.81	$1.01	$1.22	NA
Salvelinus namaycush (Lake trout)	NA	$0.01	$0.02	$0.07	$0.10	$0.18	$0.27	$0.27	$0.33	$0.39	$0.52	$0.65	$0.81	$1.01	$1.22	NA
Prosopium spp. (whitefish)	NA	$0.01	$0.02	$0.07	$0.10	$0.18	$0.27	$0.27	$0.33	$0.39	$0.52	$0.65	$0.81	$1.01	$1.22	NA
Oncorhynchus mykiss (Rainbow trout)	$0.09	$0.14	$0.15	$0.19	$0.24	$0.29	$0.35	$0.44	$0.54	$0.78	$0.90	$1.05	$1.47	$1.86	$2.25	NA
SILURIFORMES																
Ictaluridae (Freshwater catfish)																
Ictalurus furcatus (Blue catfish)	$0.02	$0.03	$0.07	$0.13	$0.15	$0.15	$0.16	$0.17	$0.22	$0.27	$0.38	$0.50	$0.56	$0.70	NA	NA
Ictalurus punctatus (Channel catfish)	$0.02	$0.03	$0.07	$0.13	$0.15	$0.15	$0.16	$0.17	$0.22	$0.27	$0.38	$0.50	$0.56	$0.70	NA	NA
Pylodictus olivaris (Flathead catfish)	$0.02	$0.03	$0.07	$0.13	$0.15	$0.15	$0.16	$0.17	$0.22	$0.27	$0.38	$0.50	$0.56	$0.70	NA	NA
Ictalurus catus (white catfish)	$0.02	$0.03	$0.07	$0.13	$0.15	$0.15	$0.16	$0.17	$0.22	$0.27	$0.38	$0.50	$0.56	$0.70	NA	NA
PERCIFORMES																
Percichthyidae (Temperate basses)																
Morone saxatilis (Striped bass)	$0.15	$0.33	$0.48	$0.64	$0.83	$0.92	$0.95	$1.02	$1.44	$1.60	$1.76	$1.92	NA			
Centrarchidae (Sunfishes)																
Micropterus salmoides (Largemouth bass)	$0.14	$0.23	$0.26	$0.35	$0.53	$0.66	$0.74	$0.92	$0.96	$1.06	$1.17	$1.28	NA			
Micropterus coosae (Redeye bass)	$0.14	$0.23	$0.26	$0.35	$0.53	$0.66	$0.74	$0.92	$0.96	$1.06	$1.17	$1.28	NA			
Micropterus punctulatus (Spotted bass)	$0.14	$0.23	$0.26	$0.35	$0.53	$0.66	$0.74	$0.92	$0.96	$1.06	$1.17	$1.28	NA			
Pomoxis nigromaculatus (Black crappie)	$0.07	$0.12	$0.16	$0.21	$0.27	$4.58	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Pomoxis annularis (white crappie)	$0.07	$0.12	$0.16	$0.21	$0.27	$4.58	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Felassoma zonatum (Banded pygmy sunfish)	$0.09	$0.11	$0.24	$0.40	$0.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Enneacanthus obesus (Banded sunfish)	$0.09	$0.11	$0.24	$0.40	$0.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis macrochirus (Bluegill)	$0.09	$0.11	$0.24	$0.40	$0.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Enneacanthus gloriosus (Bluespotted sunfish)	$0.09	$0.11	$0.24	$0.40	$0.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis marginatus (Dollar sunfish)	$0.09	$0.11	$0.24	$0.40	$0.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Centrarchus macropterus (Flier)	$0.09	$0.11	$0.24	$0.40	$0.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis cyanellus (Green sunfish)	$0.09	$0.11	$0.24	$0.40	$0.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis megalotis (Longear sunfish)	$0.09	$0.11	$0.24	$0.40	$0.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis humilis (Orangespotted sunfish)	$0.09	$0.11	$0.24	$0.40	$0.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis gibbosus (Pumpkinseed)	$0.09	$0.11	$0.24	$0.40	$0.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis auritus (Redbreast sunfish)	$0.09	$0.11	$0.24	$0.40	$0.54	NA	NA	NA	NA	NA						
Lepomis microlophus (Redear sunfish)	$0.09	$0.11	$0.24	$0.40	$0.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ambloplites rupestris (Rock bass)	$0.09	$0.11	$0.24	$0.40	$0.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

	Cost per fish (unless otherwise stated) by length of restocked fish.															
Order, Family and Species	1 in	2 in	3 in	4 in	5 in	6 in	7 in	8 in	9 in	10 in	11 in	12 in	13 in	14 in	15 in	over 15 in
Ambloplites ariommus (Shadow bass)	$0.09	$0.11	$0.24	$0.40	$0.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis punctatus (Spotted sunfish)	$0.09	$0.11	$0.24	$0.40	$0.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis gulosus (warmouth)	$0.09	$0.11	$0.24	$0.40	$0.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Stizostedion canadense (Sauger)	$0.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Stizostedion vitreum vitreum (walleye)	$0.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

* For Fish longer than 30 inches
Source: American Fisheries Society, 1990

Exhibit 4.18 Estimated costs of restocking various fish species in U.S. Fish and Wildlife Service Region 5 (in mid-1992 dollars).

	Cost per fish (unless otherwise stated) by length of restocked fish.															
Order, Family and Species	1 in	2 in	3 in	4 in	5 in	6 in	7 in	8 in	9 in	10 in	11 in	12 in	13 in	14 in	15 in	over 15 in
SALMONIFORMES																
Salmonidae (Trouts)																
Salvelinus alpinus (Arctic char)	$0.13	$0.28	$0.37	$0.59	$0.66	$0.76	$1.05	$1.22	$1.51	$1.88	$2.23	$2.64	$2.88	$3.68	$4.28	NA
Thymallus articus (Arctic grayling)	$0.13	$0.28	$0.37	$0.59	$0.66	$0.76	$1.05	$1.22	$1.51	$1.88	$2.23	$2.64	$2.88	$3.68	$4.28	NA
Coregonus spp. (Cisco)	$0.13	$0.28	$0.37	$0.59	$0.66	$0.76	$1.05	$1.22	$1.51	$1.88	$2.23	$2.64	$2.88	$3.68	$4.28	NA
Salvelinus fontinalis (Brook trout)	$0.13	$0.28	$0.37	$0.59	$0.66	$0.76	$1.05	$1.22	$1.51	$1.88	$2.23	$2.64	$2.88	$3.68	$4.28	NA
Salmo trutta (Brown trout)	$0.13	$0.28	$0.37	$0.59	$0.66	$0.76	$1.05	$1.22	$1.51	$1.88	$2.23	$2.64	$2.88	$3.68	$4.28	NA
Oncorhynchus clarki (Cutthroat trout)	$0.13	$0.28	$0.37	$0.59	$0.66	$0.76	$1.05	$1.22	$1.51	$1.88	$2.23	$2.64	$2.88	$3.68	$4.28	NA
Salvelinus namaycush (Lake trout)	$0.13	$0.28	$0.37	$0.59	$0.66	$0.76	$1.05	$1.22	$1.51	$1.88	$2.23	$2.64	$2.88	$3.68	$4.28	NA
Prosopium spp. (whitefish)	$0.13	$0.28	$0.37	$0.59	$0.66	$0.76	$1.05	$1.22	$1.51	$1.88	$2.23	$2.64	$2.88	$3.68	$4.28	NA
Oncorhynchus mykiss (Rainbow trout)	$0.12	$0.18	$0.20	$0.54	$0.62	$0.71	$0.97	$1.13	$1.39	$1.74	$1.83	$2.51	$2.92	$3.31	$3.77	NA
Esocidae (Pikes)																
Esox masquinongy (Muskellunge)	$2.13	$4.26	$6.38	$8.51	$10.64	$12.77	$14.90	$17.02	$19.15	$21.28	NA					
Esox lucius/masquinongy (Tiger muskellunge)	$2.13	$4.26	$6.38	$8.51	$10.64	$12.77	$14.90	$17.02	$19.15	$21.28	NA					
CYPRINIFORMES																
Cyprinidae (Minnows and Carps)																
Hypentelium etowanum (Alabama hog sucker)	$0.37	$0.37	$0.64	$0.64	$0.64	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Moxostoma duquesnei (Black redhorse)	$0.37	$0.37	$0.64	$0.64	$0.64	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Moxostoma poecilurum (Blacktail redhorse)	$0.37	$0.37	$0.64	$0.64	$0.64	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cycleptus elongatus (Blue sucker)	$0.37	$0.37	$0.64	$0.64	$0.64	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Erimyzon oblongus (Creek chubsucker)	$0.37	$0.37	$0.64	$0.64	$0.64	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Moxostoma erythrurum (Golden redhorse)	$0.37	$0.37	$0.64	$0.64	$0.64	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Erimyzon sucetta (Lake chubsucker)	$0.37	$0.37	$0.64	$0.64	$0.64	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Catostomus catostomus (Longnose sucker)	$0.37	$0.37	$0.64	$0.64	$0.64	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Catostomus platyrhynchus (Mountain sucker)	$0.37	$0.37	$0.64	$0.64	$0.64	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hypentelium nigricans (Northern hog sucker)	$0.37	$0.37	$0.64	$0.64	$0.64	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Moxostoma carinatum (River redhorse)	$0.37	$0.37	$0.64	$0.64	$0.64	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Moxostoma macrolepidotum (shorthead redhorse,	$0.37	$0.37	$0.64	$0.64	$0.64	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Moxostoma anisurum (Silver redhorse)	$0.37	$0.37	$0.64	$0.64	$0.64	NA	NA	NA	NA	NA	NA	NA	NA	NA		
Lepomis auritus (Redbreast sunfish)	$0.35	$0.35	$0.49	$0.65	$0.85	$1.03	$1.06	$1.60	$1.60	NA						
Lepomis microlophus (Redear sunfish)	$0.35	$0.35	$0.49	$0.65	$0.85	$1.03	$1.06	$1.60	$1.60	NA						
Ambloplites rupestris (Rock bass)	$0.35	$0.35	$0.49	$0.65	$0.85	$1.03	$1.06	$1.60	$1.60	NA						
Ambloplites ariommus (Shadow bass)	$0.35	$0.35	$0.49	$0.65	$0.85	$1.03	$1.06	$1.60	$1.60	NA						
Lepomis punctatus (Spotted sunfish)	$0.35	$0.35	$0.49	$0.65	$0.85	$1.03	$1.06	$1.60	$1.60	NA						
Lepomis gulosus (warmouth)	$0.35	$0.35	$0.49	$0.65	$0.85	$1.03	$1.06	$1.60	$1.60	NA						
Perca flavenscens (Yellow perch)	NA	$0.59	$0.59	$0.69	$1.52	$2.36	$3.19	NA								
Etheostoma spp.; Percina spp. (Darters)	NA	$0.59	$0.59	$0.69	$1.52	$2.36	$3.19	NA								

	Cost per fish (unless otherwise stated) by length of restocked fish.															
Order, Family and Species	1 in	2 in	3 in	4 in	5 in	6 in	7 in	8 in	9 in	10 in	11 in	12 in	13 in	14 in	15 in	over 15 in
Stizostedion canadense (Sauger)	$0.69	$0.69	$0.90	$1.33	$3.19	$3.19	$6.38	$6.38	$6.38	$6.38	$6.38	$7.45	NA	NA	NA	NA
Stizostedion vitreum vitreum (walleye)	$0.69	$0.69	$0.90	$1.33	$3.19	$3.19	$6.38	$6.38	$6.38	$6.38	$6.38	$7.45	NA	NA	NA	NA

Exhibit 4.19 Estimated costs of restocking various fish species in U.S. Fish and Wildlife Service Region 6 (in mid-1992 dollars).

	Cost per fish (unless otherwise stated) by length of restocked fish.															
Order, Family and Species	1 in	2 in	3 in	4 in	5 in	6 in	7 in	8 in	9 in	10 in	11 in	12 in	13 in	14 in	15 in	over 15 in
SALMONIFORMES																
Salmonidae (Trouts)																
Salvelinus alpinus (Arctic char)	NA	$0.15	$0.20	$0.27	$0.28	$0.30	$0.45	$0.63	$0.92	$0.98	$1.54	$1.95	$2.48	$3.11	NA	NA
Thymallus articus (Arctic grayling)	NA	$0.15	$0.20	$0.27	$0.28	$0.30	$0.45	$0.63	$0.92	$0.98	$1.54	$1.95	$2.48	$3.11	NA	NA
Coregonus spp. (Cisco)	NA	$0.15	$0.20	$0.27	$0.28	$0.30	$0.45	$0.63	$0.92	$0.98	$1.54	$1.95	$2.48	$3.11	NA	NA
Salvelinus fontinalis (Brook trout)	NA	$0.15	$0.20	$0.27	$0.28	$0.30	$0.45	$0.63	$0.92	$0.98	$1.54	$1.95	$2.48	$3.11	NA	NA
Salmo trutta (Brown trout)	NA	$0.15	$0.20	$0.27	$0.28	$0.30	$0.45	$0.63	$0.92	$0.98	$1.54	$1.95	$2.48	$3.11	NA	NA
Oncorhynchus clarki (Cutthroat trout)	NA	$0.15	$0.20	$0.27	$0.28	$0.30	$0.45	$0.63	$0.92	$0.98	$1.54	$1.95	$2.48	$3.11	NA	NA
Salvelinus namaycush (Lake trout)	NA	$0.15	$0.20	$0.27	$0.28	$0.30	$0.45	$0.63	$0.92	$0.98	$1.54	$1.95	$2.48	$3.11	NA	NA
Prosopium spp. (whitefish)	NA	$0.15	$0.20	$0.27	$0.28	$0.30	$0.45	$0.63	$0.92	$0.98	$1.54	$1.95	$2.48	$3.11	NA	NA
Oncorhynchus mykiss (Rainbow trout)	$0.13	$0.20	$0.22	$0.29	$0.30	$0.38	$0.52	$0.66	$0.81	$1.02	$1.19	$1.60	$2.36	$2.96	$3.56	NA
Esocidae (Pikes)																
Esox niger Chain pickerel	$0.11	$0.11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Esox americanus vermiculatus (Grass pickerel)	$0.11	$0.11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Esox lucius (Northern pike)	$0.11	$0.11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Esox americanus americanus (Redfin pickerel)	$0.11	$0.11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SILURIFORMES																
Ictaluridae (Freshwater catfish)																
Ictalurus furcatus (Blue catfish)	$0.07	$0.09	$0.10	$0.10	$0.11	$0.16	$0.17	$0.26	$0.36	$0.50	$0.66	$0.86	$1.27	$1.36	NA	
Ictalurus punctatus (Channel catfish)	$0.07	$0.09	$0.10	$0.10	$0.11	$0.16	$0.17	$0.26	$0.36	$0.50	$0.66	$0.86	$1.27	$1.36	NA	
Pylodictus olivaris (Flathead catfish)	$0.07	$0.09	$0.10	$0.10	$0.11	$0.16	$0.17	$0.26	$0.36	$0.50	$0.66	$0.86	$1.27	$1.36	NA	
Ictalurus catus (white catfish)	$0.07	$0.09	$0.10	$0.10	$0.11	$0.16	$0.17	$0.26	$0.36	$0.50	$0.66	$0.86	$1.27	$1.36	NA	
PERCIFORMES																
Centrarchidae (Sunfishes)																
Micropterus salmoides (Largemouth bass)	$0.11	$0.15	$0.30	$0.40	$0.71	$0.99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Micropterus coosae (Redeye bass)	$0.11	$0.15	$0.30	$0.40	$0.71	$0.99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Micropterus punctulatus (Spotted bass)	$0.11	$0.15	$0.30	$0.40	$0.71	$0.99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Micropterus dolomieui (Smallmouth bass)	$0.11	$0.14	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Pomoxis nigromaculatus (Black crappie)	NA	$0.18	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Pomoxis annularis (white crappie)	NA	$0.18	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Felassoma zonatum (Banded pygmy sunfish)	$0.07	$0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Enneacanthus obesus (Banded sunfish)	$0.07	$0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis macrochirus (Bluegill)	$0.07	$0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Enneacanthus gloriosus (Bluespotted sunfish)	$0.07	$0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis marginatus (Dollar sunfish)	$0.07	$0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Centrarchus macropterus (Flier)	$0.07	$0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis cyanellus (Green sunfish)	$0.07	$0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis megalotis (Longear sunfish)	$0.07	$0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Order, Family and Species	Cost per fish (unless otherwise stated) by length of restocked fish.														
	1 in	2 in	3 in	4 in	5 in	6 in	7 in	8 in	9 in	10 in	11 in	12 in	13 in	14 in	15 in	over 15 in
Lepomis humilis (Orangespotted sunfish)	$0.07	$0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis gibbosus (Pumpkinseed)	$0.07	$0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis auritus (Redbreast sunfish)	$0.07	$0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis microlophus (Redear sunfish)	$0.07	$0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ambloplites rupestris (Rock bass)	$0.07	$0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ambloplites ariommus (Shadow bass)	$0.07	$0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis punctatus (Spotted sunfish)	$0.07	$0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lepomis gulosus (warmouth)	$0.07	$0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Stizostedion canadense (Sauger)	$0.11	$0.11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Stizostedion vitreum vitreum (walleye)	$0.07	$0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

* For Fish longer than 30 inches
Source: American Fisheries Society, 1990

The fish replacement costs presented in the American Fisheries Society handbook (Riely et al., 1990) and in Exhibits 4.13 through 4.19 include only the cost of purchasing the fish from a hatchery. The transportation costs are calculated separately based on the per-mile cost stated above and should be added to the cost of obtaining the fish. The labor and other expenses related to the restocking activities, however, are not included in the handbook. These costs would need to be estimated by the hatchery conducting the operation.

The fish hatchery development and operation costs from the U.S. Fish and Wildlife Service handbook are stated per pound of fish released from the hatchery (Nelson et al., 1978). Although the capital costs were amortized for 20 years, this lump sum of $46.97 (in mid-1992 dollars) per pound of fish raised would still need to be presented at the time of implementation. An additional limitation on the use of these costs, besides the age of the data, is that the type of fish raised in these hatchery projects is unknown. Costs can vary substantially based on the type of fish grown.

4.3.2.3.3 Fishery Habitat Restoration and Enhancement

There are two fishery habitat enhancement actions for which the literature provides the costs associated with implementation. These methods include the construction of artificial reefs and improvement of fish passageways. A detailed discussion on each of these actions located in Section 2.3.2.3.3.

Several studies document the costs involved with constructing and deploying artificial reef structures. Exhibit 4.20 presents the structural dimensions, unit costs, and installation costs for 12 artificial reef structures. All of the cost estimates were converted into mid-1992 dollars. There exist several other artificial reef structure types for which the literature fails to provide estimated costs.

The most expensive artificial reef structure is the polyolefin plastic cone at approximately $7,400 per unit. This design is manufactured from 2 cm thick cross-linked polyolefin plastic resin specifically for the purpose of artificial reefs (Bell et al., 1989). Whereas, the triangle tire unit is the least expensive structure at $3.77 each because of the simple design, construction process, and low material requirements (Prince and Maughan, 1978). The installation costs presented in Exhibit 4.20 have some correlation between the relative cost and type of labor and equipment required for deployment. For example, the reef structures requiring specialized equipment (i.e., forklift, crane) and substantial manual labor will cost more to install than those units that require less complicated logistics (Bell et al., 1989).

Exhibit 4.20 Estimated costs of artificial reef structures (in mid-1992 dollars).

Type of Artificial Reef	Dimensions of Reef Structure (in (meters)	Cost per Reef Structure	Installation Cost per Reef Structure	Source
Brush Shelters	10.7 Diameters/6.1 H	$131.44	*	Nelson et al (1978)
Concrete Igloos	NA	$1,332.00	NA	Feigenbaum et al. (1989)
Concrete, Rubble, and Riprap Rock Pile	10.7 Diameter/3.05 H	$6,679.14	*	Knatz (1987)
Modified Concrete Docks and PVC Plastic	3.0L/1.5 W/1.8 H	$1,000.15	$150.63	Bell et al. (1989)
Polyolefin Plastic Cone	NA	$7,383.42	$248.60	Bell et al. (1989)
Polyolefin Plastic Hemisphere	1.8 Diameter	$1,777.49	$124.30	Bell et al. (1989)
1.1 m Steel Reinforced Concrete Pipe	0.9 Diameter/2.4 L	$223.52	$207.01	Bell et al. (1989)
1.6 m Steel Reinforced Concrete Pipe	1.4 Diameter/1.2 L	$236.18	$292.82	Bell et al. (1989)
Structural Stele Cube	1.5 L/1.5 W/1.5 H	$274.74	$53.02	Bell et al. (1989)
Modified Steel Cube and Plastic Mesh	1.5 L/1.5 W/1.5 H	$298.84	$48.20	Bell et al. (1989)
Tires-in-Concrete	1.9 L/1.5 W/1.1 H	$108.45	$106.04	Bell et al. (1989)
Tires-in-Concrete	0.61 L/0.76 W/0.15H	$8.88	NA	Feigenbaum et al. (1989)
Triangle Tire Unit	NA	$3.77	$1.65	Prince and Maughan (1978)

* The cost of installation is included in the reef structure cost.

Nelson et al. (1978) provide estimated costs associated with two fish passageway improvements techniques; trap and haul systems, and fishways. These costs are based on a compilation of actual case studies related to each passageway improvement option were inflated to represent mid-1992 dollars. The average cost of constructing and installing a trap and haul system, based on three actual projects, was $4.5 million, with operation and maintenance costs at approximately $52,000 per year. Fishways, which include various fish ladder designs, are substantially more expensive to develop. The average construction and installation cost, based on two actual project budgets, was $15.8 million.

4.3.2.3.4 Modification of Management Practices

The literature does not provide the costs associated with this restoration action.

4.3.2.3.5 Habitat Protection and Acquisition

The literature does not provide the costs associated with this restoration action.

4.3.3 Reptiles

There exist three actions for restoring injured reptile habitats and populations. These actions include:

- Natural Recovery;
- Restocking/Replacement; and
- Protection of Nest Sites.

4.3.3.1 Oil Related Literature

After an extensive search of oil related restoration literature, no sources were located that discussed the costs of restoring reptile populations to baseline conditions following an oil discharge incident.

4.3.3.2 Non-oil Related Literature

A report developed by International Animal Exchange, Inc. (1992) provides the cost estimates and availability to deliver live wildlife specimens from captive sources for the purpose of reintroduction to the wild in U.S. territories and estimated cost to obtain, transport, and acclimate wildlife specimens from the wild. The estimated costs of restocking an affected reptile population with captive raised reptiles or reptiles relocated from another location are discussed below in Section 4.3.3.3.2.

4.3.3.3 Cost of Restoration Actions

The following paragraphs discuss the estimated costs involved with restoration of reptiles injured or destroyed by oil contamination. The actions include:

- Natural Recovery;
- Restocking/replacement; and
- Protection of Nest Sites.

4.3.3.3.1 Natural Recovery

Section 4.4 provides a description of the costs of monitoring programs.

4.3.3.3.2 Restocking/Replacement

Before restocking or replacement can occur, the habitat must be restored and free from contamination enough to support any reptile species reintroduced into the environment.

This section provides estimated costs associated with the process of restocking or replacing various reptile species. These costs were obtained from the report provided by International Animal Exchange, Inc. (1992) and are presented on a per unit basis. These costs and the associated assumptions or considerations are discussed below.

According to the report by International Animal Exchange, Inc. (1992), there exist seven reptile species that can potentially be relocated from one location to another location in the wild. Of these seven, however, only one species, the American alligator, can be raised in captivity and released into the wild. The estimated costs per animal in mid-1992 dollars of both the captive raised alligator and species that can be relocated are provided in Exhibit 4.21. The costs for relocated reptiles range from $2,400 per specimen for an Atlantic loggerhead turtle to $7,800 per specimen for a Pacific ridley turtle. The cost of a captive raised American alligator is $2,600 per specimen.

There are several assumptions associated with the costs provided in the previous section: no licenses or permit fees are included in the stated cost; values for the animals relocated from another location in the wild are based on relocating a minimum of 10 specimens of a species; and costs include transportation, personnel, supplies, and equipment expenses.

Exhibit 4.21 Estimated costs of restocking reptiles (in mid-1992 dollars).

		Cost per animal	
Family	**Species**	**Captive Raised**	**Relocated from Wild**
Cheloniidae	Atlantic Loggerhead turtle	NA	$2,400
	Pacific Loggerhead turtle	NA	$2,800
	Atlantic ridley turtle	NA	$6,900
	Pacific ridley turtle	NA	$7,800
Dermochelyidae	Atlantic leatherback turtle	NA	$6,600
	Pacific Sea leatherback turtle	NA	$4,600
Crocodylidae alligatorinae	American Alligator	$2,600	$3,200

NA = Not Applicable
Note: Please refer to text for related assumptions and to Section 2.3.3 for the availability of captive raised reptiles.

Source: International Animal Exchange, 1992

4.3.3.3.3 Protection of Nest Sites

The literature does not provide the costs associated with this restoration option.

4.3.4 Birds

There exist five actions for restoring injured bird habitats and populations. These actions include:

- Natural Recovery;
- Restocking/Replacement;
- Habitat Restoration and Enhancement;
- Modification of Management Practices; and
- Habitat Protection and Acquisition.

4.3.4.1 Oil Related Literature

After an extensive search of oil related restoration literature, no sources were located which discussed the economic costs of restoring bird populations.

4.3.4.2 Non-oil Related Literature

As described in Section 4.3.3.2., International Animal Exchange, Inc. (1992) developed a report which provides cost estimates of relocating or restocking various wildlife species. A majority of the species included are birds. The costs associated are discussed in detail in Section 4.3.4.3.2.

4.3.4.3 Estimated Costs of Restoration Actions

The following paragraphs discuss the estimated costs involved with restoration of bird communities injured or destroyed by oil contamination. The actions include:

- Natural Recovery;
- Restocking/Replacement;

- Habitat Restoration and Enhancement;
- Modification of Management Practices; and
- Habitat Protection and Acquisition.

4.3.4.3.1 Natural Recovery

Section 4.4 provides a description of the costs of monitoring programs.

4.3.4.3.2 Restocking/Replacement

Before restocking or replacement of birds can occur, the habitat must be restored and free enough from contamination to support any bird species reintroduced into the environment.

This section provides estimated costs associated with the process of restocking or replacing various species of birds. These costs were obtained from the report provided by International Animal Exchange, Inc. (1992) and are presented on a per unit basis. These costs and associated assumptions or considerations are discussed below.

According to the report by International Animal Exchange, Inc. (1992), there exist 88 species of birds that can potentially be relocated from one location in the wild to another location. Of these 88 species, however, only 24 species can be raised in captivity and released into the wild. The estimated costs per bird in mid-1992 dollars of both the captive raised species and species that can be relocated are provided in Exhibit 4.22. The costs for relocated birds range from $200 per bird for gulls or terns to $3,800 per bird for American flamingos. The costs of obtaining captive raised birds range from $200 per bird for ducks to $4,400 per bird for American white pelicans.

There are several assumptions associated with the costs provided in the previous section: no licenses or permit fees are included in the stated cost; costs for the birds relocated from the wild to another location are based on relocating a minimum of 100 specimens of a species; and costs include transportation, personnel, supplies, and equipment expenses.

4.3.4.3.3 Habitat Restoration and Enhancement

The literature does not provide the costs associated with this restoration option. However, habitat restoration costs provided earlier in this Section may be applicable, depending on the particular actions performed.

Exhibit 4.22 Estimated costs of restocking birds (in mid 1992 dollars).

Family	Species	Cost per animal	
		Captive Raised	Relocated from Wild
Caviidae	Common loon	NA	$330
Podicipedidae	Horned grebe	NA	$370
	Red necked grebe	NA	$410
Domedeidae	Laysan albatross	NA	$810
	Black footed albatross	NA	$810
Procellariidae	Northern fulmar	NA	$790
	Japanese petrel	NA	$805
	Hawaiian petrel	NA	$690
	Greater shearwater	NA	$705
	Sooty shearwater	NA	$640
	Manx shearwater	NA	$640
	Shorttailed shearwater	NA	$640
Hydrobatidae	Least storm petrel	NA	$510
	White-vented storm petrel	NA	$510
	Band-rumped storm petrel	NA	$510
	Ashy storm petrel	NA	$510
	Ringed storm petrel	NA	$570
	Leachs storm petrel	NA	$690
Pelecanidae	American white pelican	$4,400	$2,400
	Brown pelican	$1,900	$920
Sulidae	Northern gannet	NA	$790
	Blue-footed booby	NA	$810
Phalacrocoracidae	Double crested cormorant	NA	$960
	SW Double crested cormorant	NA	$960
	NW Double-crested cormorant	NA	$960
	Common (great) cormorant	$710	$860
	Northern great cormorant	NA	$960
	Olivaceous cormorant	NA	$960
Ardeidae	American bittern	NA	$710
	Great blue heron	$2,200	$2,400
	Green heron	NA	$2,400
	Tricolored heron	NA	$2,400
	Black browned night heron	NA	$1,810
	Night heron	NA	$1,810
	Yellow-crowned night heron	NA	$1,810
	Cattle egret	$300	$305
	Snowy egret	$890	$405
Threskiornithidae	American white ibis	$690	$405
	Scarlet ibis	$700	$940
	Bare-faced ibis	NA	$640
	White-faxed ibis	NA	$640
	Glossy ibis	$590	$640
	Roseate spoonbill	$1,100	$1,400
Phoenicopteridae	American Flamingo	$2,100	$3,800
Anatidae	White-fronted goose	$600	$890
	Tule goose	NA	$850

	Graylag goose	$710	$850
	Snow goose	$450	$590
	Greater snow goose	NA	$710
	Lesser snow goose	$490	$710
	Emperor goose	$850	$975
	Ross goose	$710	$840
	Lawrences brant goose	NA	$840
	Pacific brant goose	NA	$840
	Canada goose (generic)	$360	$490
	Whistling swan	NA	$1,200
	Trumpeter swan	$1,200	$1,400
	Duck (most species; generic)	$200	$370
Accipitridae	Hawk/Eagle (most species; generic)	NA	$2,400
Gruidae	Whooping crane	NA	$1,640
	Sandhill Crane	$1,000	$1,340
	Lesser sandhill crane	$1,000	$1,340
	Florida sandhill crane	$1,000	$1,340
	Mississippi sandhill crane	NA	$1,640
	Canadian sandhill crane	NA	$1,640
	Greater sandhill crane	NA	$1,640
Aramidae	Limpkin	NA	$810
Rallidae	Rail/coot (most species; generic)	NA	$410
Haematopodidae	American oystercatcher	NA	$490
Recurvirostridae	Hawaiian stilt	NA	$490
	Black winged stilt	NA	$490
	Black necked stilt	NA	$490
	American avocet	NA	$590
Charadriidae	Lesser golden plover	NA	$590
	Black bellied plover	NA	$590
Scolopacidae	Spotted sandpiper	NA	$470
	Upland sandpiper	NA	$470
	Willet	NA	$470
	Wandering tattler	NA	$670
	Godwit	NA	$670
	Long-billed curlew	NA	$740
	Lesser yellowlegs	NA	$490
	Greater yellowlegs	NA	$490
	Solitary sandpiper	NA	$710
	Black turnstone	NA	$910
	Andean snipe	NA	$910
Laridae	Gull/Turn (most species; generic)	NA	$200
Alcidae	Puffin (most specific; generic)	$2,100	$1,960

NA = Not available
Note: Please refer to test for related assumptions and to Section 2.3.4 for the availability of captive raised birds.
Source: International Animal Exchange, 1992.

4.3.4.3.4 Modification of Management Practices

The literature does not provide the costs associated with this restoration option.

4.3.4.3.5 Habitat Protection and Acquisition

The literature does not provide the costs associated with this restoration option.

4.3.5 Mammals

There exist five actions for restoring injured mammal habitats and populations. These actions include:

- Natural Recovery;
- Restocking/Replacement;
- Habitat Restoration and Enhancement;
- Modification of Management Practices; and
- Habitat Protection and Acquisition.

4.3.5.1 Oil Related Literature

After an extensive search of oil related restoration literature, no sources were located which discussed the economic costs of restoring mammal populations.

4.3.5.2 Non-oil Related Literature

As described in Section 4.3.3.2., International Animal Exchange, Inc. (1992) developed a report which provides availability levels of various wildlife species. The estimated costs of restocking are discussed in detail in Section 4.3.5.3.2.

4.3.5.3 Estimated Cost of Restoration Actions

The following paragraphs discuss the estimated costs involved with restoration of mammals injured or destroyed by oil contamination through natural recovery and restocking/replacement.

4.3.5.3.1 Natural Recovery

Section 4.4 provides a description of the costs of monitoring programs.

4.3.5.3.2 Restocking/Replacement

Before restocking can be undertaken the habitat must be restored and free from contamination enough to support any mammal species reintroduced into the environment, and an assessment of the lost mammal species must be conducted to determine the related costs for this restoration option.

This section provides estimated costs associated with the process of restocking or relocating various species of mammals. These costs were obtained from the report provided by International Animal Exchange, Inc. (1992) and are presented on a per unit basis. These costs and associated assumptions or considerations are discussed below.

According to the report by International Animal Exchange, Inc. (1992), there exist 27 species of mammals that can potentially be relocated from one location in the wild to another location. Of these 27 species, however, only 7 species can be raised in captivity and released into the wild. The estimated costs per mammal in mid-1992 dollars of both the captive raised species and species that can be relocated are provided in Exhibit 4.23. The costs for relocated mammals range from $200 per specimen for muskrats to $235,000 per specimen for Northern right-whale dolphins. The costs of obtaining captive raised mammals range from $4,000 per specimen for Northern fur seals to $65,000 per specimen for bottle-nosed dolphins.

The assumptions associated with the costs provided in the previous section include: no licenses or permit fees are included in the stated cost; values for the animals relocated in the wild are based on relocating a minimum of 10 specimens of a species; and costs include transportation, personnel, supplies, and equipment expenses.

4.3.5.3.3 Habitat Restoration and Enhancement

The literature does not provide the costs associated with this restoration option. However, habitat restoration costs provided earlier in this section may be applicable, depending on the particular actions performed.

4.3.5.3.4 Modification of Management Practices

The literature does not provide the costs associated with this restoration action.

4.3.5.3.5 Habitat Protection and Acquisition

The literature does not provide the costs associated with this restoration action.

Exhibit 4.23 Estimated costs of restocking mammals (in mid-1992 dollars).

Family	Species	Captive Raise	Relocated from wild
Cricetidae	Muskrat	NA	$200
Delphinidae	Killer whale	NA	$160,000
	False killer whale	NA	$100,000
	Northern right-whale dolphin	NA	$235,000
	Saddle back dolphin	NA	$25,000
	Common dolphin	NA	$40,000
	Risso's dolphin	NA	$40,000
	White-sided dolphin	NA	$30,000
	Pacific white-sided dolphin	NA	$30,000
	Gill's bottle-nosed dolphin	NA	$40,000
	Bottle-nosed dolphin	$65,000	$35,000
	Pacific harbour porpoise	NA	$49,000
	Dall's porpoise	NA	$61,000
Monondontidae	Beluga whale	NA	$49,000
Ursidae	Polar bear	$20,000	$35,000
Mustelidae	Northern sea otter	$23,000	$13,000
	Southern sea otter	NA	$16,000
Otariidae	Northern fur seal	$4,000	$4,000
	Steller's northern sea lion	NA	$17,000
	California sea lion	$5,000	$4,000
	Walrus	NA	$39,000
	Bearded seal	NA	$24,000
	Grey seal	$5,000	$11,000
	Harbor seal	$5,000	$11,000
	Northern elephant seal	NA	$16,000
	Hawaiian monk seal	NA	$11,000
Trichechidae	Manatee	NA	$16,000

NA = not available
Note: Please refer to text for related assumptions and to Section 2.3.5 for the availability of captive raised mammals.
Source: International Animal Exchange, 1992

4.4 Monitoring Costs

In practice, a systematic monitoring program, with mechanisms to assess the effectiveness of the restoration strategy and, if necessary, make mid-course adjustments to that strategy is critical. The literature consistently recognizes the significance of implementing a reliable monitoring program as an integral part of the restoration process (Broome, 1990; Gore and Bryant, 1988; Josselyn et al., 1990; Lewis, 1990; and Nur and Ainley, 1992).

In establishing monitoring costs it must be remembered that monitoring program costs do not include those costs associated with environmental assessment activities associated with the damage assessment process. In a similar fashion, the analysis of the site which may be necessary to design and implement a restoration strategy are not monitoring costs. When the study and research costs associated with implementing a restoration option have been available, they have been captured in the unit costs of conducting the initial restoration activities presented in this section. The limited literature that directly estimates the costs associated with implementing a monitoring program are summarized below:

- **Artificial reef monitoring**. Knatz (1987) describes an artificial reef extension project in southern California. Due to the uncertainty of the project, the California Coastal Commission required the implementation of a two-year biological monitoring program. The costs of this program were estimated near $86,450 per hector (in 1992 dollars);

- **Liming program monitoring**. Watt (1986) describes a liming program in Nova Scotia. The objective of the program is to increase the pH level in several rivers to restore the declining Atlantic salmon stocks. The program duration is 20 years. The estimated cost for project management and scientific monitoring, which includes biological and chemical monitoring, is $621,500 per year (in 1992 dollars); and

- **Sediment monitoring.** The costs of sampling sediments for residual oil contamination are more readily available than those for other habitats because these tests are routinely preformed as part of the permitting process for dredging rivers and harbors. The collection of sediment samples for one area requires one to two days of sampling effort. Meyers et al. (1991) estimates sampling costs of $1,000 to $10,000 per day for boat rental plus an additional $1,000 to $3,000 per day for labor. For a generic sampling plan, Pequegnat et al. (1990) estimates vessel costs at approximately $8,700 per day, and scientist labor at $5,000 to $6,000. The New York/New Jersey Port Authority estimates their 1992 sampling costs at approximately $5,000 per mobilization and $1,500 per day of operation. Based on the above information, sampling costs for about five to eight sampling stations range from $2,000 to $15,000 per day. The number of samples required would vary substantially by the size of area being monitored, and the hydrological characteristics of the affected environment. Absent a large or complex sampling plan, one day of sampling effort would be adequate to cover a relatively large affected area of between 10 to 50 square miles

The more substantial costs are for analyzing and evaluating the results. The minimal test for organic pollutants average $1,200 per sample (EPA ERL-N 1991; Pequegnat et al, 1990) and simply represents the measurement of residual oil. Additional tests which could be required, depending on the nature of the concern, are as follows;

- The 96-hour elutriate bioassay with mysid shrimp is between $1,000 to $2,340 per sample (Meyers et al., 1991; NY/NJ Port Authority, 1992).

- 10-day benthic toxicity test with infaunal amphipod is between $400 and $4,207 per sample (Meyers et al., 1991; EPA ERL-N, 1991; NY/NJ Port Authority, 1992).

- 28-day bioaccumulation test, without chemical analysis of tissues, using a polychaete worm is $2,000 to $5,950 (Meyers et al., 1991; NY/NJ Port Authority, 1992).

Assuming five sediment samples and the simple bioassay analysis, monitoring costs could be as low as $5,000, but are expected to average approximately $20,000 per annum. If additional samples were taken and the more complex tests required, the total costs would be on the order of $40,000 to $125,000 per annum.

It should be cautioned that sediment monitoring tests would vary depending on the nature of the sediments, type of contamination and types of resources being monitored. Testing would at a minimum include testing for the simple presence of contamination. If the concern extended to the toxic effects on benthic species, more complex tests are available including a elutriate bioassay test with mysid shrimp, the benthic toxicity test using infaunal amphipod, or bioaccumulation tests with worms. These more complex tests would only be warranted in situations were there were substantial concerns over the contamination of sediments and represent an upper bound of costs.